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TRANSACTIONS

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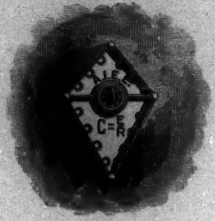

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Vol
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AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

NEW YORK, October 21st, 1896.

The 109th meeting of the INSTITUTE was held this date, at 12 West 31st Street, and was called to order by President Duncan at 8.10 P. M.

The Secretary announced the election of the following associate members by the Executive Committee at the meeting in the afternoon.

Name.	Address.	Endorsed by,
BENOLIEL, SOL D.	1327 Broadway, residence, 120 W. 35th Street, New York City.	Geo. F. Sever. F. B. Crocker. W. H. Freedman.
FISH, MILTON L.	Ass't Manager, Pasadena Electric Light and Power Co., Pasadena, Cala.	Chas. R. Cross. Wm. L. Puffer. H. V. Hayes.
RICE, ARTHUR L.	Professor of Steam and Electrical Engineering, Pratt Institute, Brooklyn, N. Y.	Harold B. Smith. A. S. Kimball. H. J. Ryan.

Total 3.

THE PRESIDENT:—This evening we have a topical discussion on "Electric Traction under Steam Railway Conditions," to be opened by Dr. Charles E. Emery.

A Topical Discussion at the 109th Meeting of the American Institute of Electrical Engineers, New York, October 21st, and Chicago, October 28th, 1896.

ELECTRIC TRACTION UNDER STEAM RAILWAY CONDITIONS.

(A Topical Discussion.)

Opening Remarks by Dr. Chas. E. Emery.

In accepting an invitation to open this discussion upon general lines, it appeared necessary to make an investigation to ascertain in a general way the outcome of an attempt to introduce electric traction on our trunk line railways, in view of the rapid improvements that have been made in electrical apparatus, and the reduction of cost that has followed the greater demand.

In the light of recent achievements, it can be assumed at the outset that electric traction under steam railway conditions is feasible. The only question is whether it will pay. The present applications only prove the former proposition, but do not touch the latter.

Electric traction on street railways was commercially successful because it gave increased power by comparatively simple means, and the actual cost of operation was less than formerly with horses, so that the saving in this respect, and the increased travel due to better facilities, warranted the enormous development which has taken place in this direction. The application of electric locomotives for suburban traffic underground, as on the City and South London Railway and on a branch surface road to Nantasket Beach, near Boston, with other somewhat similar applications, show the practicability, desirability and financial success of electric traction for such service. The Baltimore tunnel application shows that electric power may be transmitted and utilized in very large units successfully, and the freedom from escaping gases warrants the application at that particular location without further investigation. In suburban traffic a certain flexibility is necessary by which large crowds may be taken when desired; and if the comfort of the transit can be so increased as to make frequent trips desirable to travelers, the business will be built up and the heavy expenditures necessary to change to electricity be compensated for in this way, even on

the present steam operated roads for considerable distances from large business centres. It does not seem probable, however, under present conditions, that any probable increase of travel will warrant the enormous outlay necessary to secure electric traction throughout the whole length of our trunk railroads.

The greatest practical efficiency of an electric system of the kind proposed between the engines at the central station and the rails would probably be 60 per cent. This, on account of a second transmission to sub-stations and the necessity of using rheostatic regulation to some extent, would probably be reduced to 50 per cent., so that twice as many horse-power would need to be generated at the central station as at the track with the present steam locomotives. Each horse-power in the central station will be developed for two pounds of cheap coal or four pounds per net H.P. delivered, whereas the steam passenger locomotive will on the average require six pounds, based on net tractive force and allowing for the various wastes. The saving in coal due to electric passenger traction will therefore be one-third. Coal is procured cheaply by the railroads, but probably an inferior quality costing 50 cents per ton, or say 25 per cent. less than that used on locomotives, could be employed in the electric stations, so that, for trains of like weight, the saving in *cost* of coal for passenger service would be $\frac{4}{6} \times \frac{3}{4} = \frac{1}{2}$. For freight engines we calculate the saving in cost for fuel will be about 55 per cent., and for switching engines about 66⅔ per cent. On railroads running through the coal regions the total cost of coal is about 9 per cent. of the total operating expenses. A saving of one-half in the cost of the coal then corresponds to a saving of 5 per cent. of operating expenses. For reasons that will be stated later, it is believed that, for general railroad work, independent electric locomotives will be required, and that these will necessarily be as heavy as present steam locomotives, on which basis the only saving in weight will be that of the tender, which we have assumed as 10 per cent. of the total weight of the train for passenger engines, 3.3 per cent. for freight engines, and 5 per cent. for switching engines. The total load to be hauled will therefore be decreased by these several percentages, and the cost of coal reduced thereby to 45 per cent. of that required by the present locomotives for passenger trains; 43½ per cent. for freight trains, and 32 per cent. for switching trains. Applying these percentages for the relative amounts of coal used for these different purposes on a prominent railroad, the average saving in fuel becomes 58.9 per cent. or 5.89 per cent. of operating expenses. The cost of water is taken at ⅛ of 1 per cent. on the same basis, which increases the saving to 6.56 per cent.

Considerable savings have been claimed on other grounds. First, in relative repairs of electric motors compared with locomotives. Repairs will be less on the motors of course, but are not inconsiderable, and when we consider that the transmission

line, trolley line and trolleys must be kept in repair as well as the motors, it cannot be far in error to assume that the question of repairs will be about balanced, independent of central station apparatus otherwise provided for.

It has been claimed that labor will be saved because the second man on an electric locomotive is required simply to provide for sickness or accident of the driver, and can well be the baggage-man of a passenger train or the conductor of a freight train. Something of this kind may be worked out on an unimportant country road, but it would be impracticable on a large business scale. If a trunk line were to be changed to electricity to-morrow the best policy would be to keep the old engineers to operate the locomotives and learn of electricity as fast as possible, and to put the young men from the training schools of the large companies as the second men to watch electrical details and overcome unforeseen contingencies, the firemen taking their places as they learn how. It is also claimed that there will be a saving in the weight and cost of electric locomotives, particularly when applied under a car, but this system is of limited application. Heavy locomotives on trunk lines must have the same weight for electric as for steam traction, independent of the tender, as explained hereafter. Large savings in repairs to tracks and bridges are also claimed on account of the smoothness with which electric locomotives having no reciprocating parts would operate. The same weights must be run over the same rails at the same speed, and at least a great part of the wear and tear would be due to inequalities of the track surface which would influence both systems alike. The present locomotives are so designed that, while the wheel loads on the drivers are heavy, the masses which strike blows are comparatively light; that is, they have simple wheels and axles, spring-connected to the frames. This is a very difficult thing to accomplish with an electric locomotive without using exactly the same construction. On a comparatively smooth track, remarkable steadiness of movement may be obtained, if the armatures of the motors are secured to the axles of the driving wheel and the fields supported concentric therewith, but such an arrangement is entirely unfitted for a railroad track in average condition. Springs only relieve the frame. Each pair of wheels and attached motor acts as an enormous trip-hammer on the rails and roadbed the moment the former gets the least out of alignment, by defect in original construction, by settling after rains or from other causes. A connection to driving axles through gearing reduces the blows very materially, but introduces at high speed another difficulty. The vertical movements of the main axle would necessarily cause a change in the angular velocity of the armature during the time of such movement, which, for jars occurring in the fraction of a second, would bring a heavy strain on the gearing and vary the speed of the armature momentarily.

The variations in current due to such variation may also give a longitudinal pulsation to the train. The matter is not helped at all by mounting the motors on hollow axles concentric with the driving axles so that the motors may be spring-supported from the axles, for in such case the connection of the motor to the axles must be through links the equivalent of a universal joint, which produce variations in velocity, when the axles are out of centre with the armature, similar to those where gearing is employed. In fact, these very devices are used to obtain variation in angular velocity in many machines. Either gearing or universal joints would have back lash when current was shut off. The suggestion recently occurred to the speaker, and he has not had time to calculate the effect of these considerations, but they must be serious. A train at 60 miles an hour moves about 90 feet a second, sufficient to cover a number of yielding rail joints in that time. When the New York Central Railroad started its fast trains, the engineer found it necessary to go over the alignment with instruments; as dips and vertical curves, which would not be noticed by the trackmen, gave very unpleasant motions to the cars at high speed.

For reasons above given, it will be necessary to mount electric motors for fast locomotives away from the centres of the axles and connect through side rods, as in the present locomotives. The only other method would be to use chains, which are mechanically impracticable. There is another important reason for this. In order to obtain speed the motors must be wound for it so that the counter-electromotive-force will be produced by velocity rather than the number of turns, and, in starting, the motors are necessarily connected in series so as to reduce the starting current. For motors adapted to very high speeds, it will be necessary to put pairs in series even to surmount heavy grades, to act as pushers in case of accident, or in removing snow, etc. The counter-electromotive-force is therefore divided between several motors, but not necessarily in equal degree. If, with motors connected to separate axles, one for any reason slips its wheels, it will monopolize the larger portion of the electromotive force and cut down the current on all the motors in series so that full power cannot be obtained. Working the motors in parallel with an enormous rheostat would be wasteful and, in some cases, impracticable. It is, therefore, important for two reasons to connect driving wheels operated by separate motors by means of side rods.

Again, it is essential that, on the road, speed be regulated by better means than a rheostat. A series motor varies its speed with the load and so cannot run without rheostatic regulation at a given speed if for any reason the number of cars in the train or the track resistance varies. It will, therefore, be necessary to return to commuted series field coils or equivalents, and it will be perhaps desirable to have a shunt winding which can be used

to give still closer regulation. In fact, shunt motors are being introduced abroad for traction purposes. The use of these devices will increase the weight of the motors compared with simple series wound motors, for the simple reason that with the field reduced to the utmost it must still be sufficient to prevent sparking, and there must be sufficient iron employed to make the stronger field efficient when it is desirable to run slower. These considerations make more room desirable for the motors than can be provided in the trucks of an ordinary car.

For these several reasons it is predicted that the high speed electric locomotive of the future will, like the steam locomotive, be a structure independent of the train, that the motors will be hung on the frame independent of the driving wheels, and the same as well as the driving wheels connected by side rods. To obtain proper room under such conditions larger driving wheels will be employed than the wheels of an ordinary car. This will so extend the wheel base that it will not be safe to run at high speeds without the leading truck the same as on an ordinary locomotive, and in fact the electric locomotive will in all its general features be a steam locomotive without the boiler, with motors substituted for the steam cylinders. In this way and probably in no other can the flexibility of the present steam locomotive be obtained. Probably there will be greater difference of opinion on this subject than on any other. The use of motors in the trucks of baggage cars is so fascinating that strong efforts will be and should be made to retain such a system, though the reasons stated are believed to be sufficient to prevent its general adoption. Again, it is desirable that the whole locomotive be a unit, on a strong frame calculated to resist the shocks due to collisions and accidents, and it is doubtful if locomotive drivers will be found who will be willing to risk their lives on any other kind of a structure.

To realize the flexibility of the ordinary locomotive, one has but to go on the line of one of the roads which has not yet adopted the heaviest type of rail, but yet runs express trains at 45 miles per hour, grasp a convenient post close to the line and a little around a curve, if possible, where one can take the wind of the train, and watch its approach. In many cases the locomotive sways nearly a foot from the perpendicular, first one way and then the other. At a bad joint the plunge is so rapid that the effect can be described as terrific, as one cannot but think of the consequences if such a mass should leave the rails. The locomotive, however, follows the inequalities as readily as would a farm wagon. Electrical engineers may insist upon a more rigid and better track, but this will require additional expense and will not entirely overcome the difficulty. The electric locomotive must be constructed so that it will do the work of the present locomotive in the same way, and the feature of flexibility cannot be sacrificed.

A modern heavy locomotive costs about $10,000, which is at the rate of $10 to $12 per H.P., on about the same basis as electric motors would be rated. It needs little argument to show that an electric locomotive to take its place under conditions stated would cost fully as much. Moreover, if like care is to be taken of electric locomotives as of those for steam, the same number must be employed of like capacity for like work.

An approximate calculation of the cost of electrically equipping and operating a trunk line has been based on information in regard to the operating expenses of different railroads, given in the series of articles by Mr. Baxter, in the *Electrical Engineer* early this year. We have the highest respect for the industry and ingenuity of Mr. Baxter, as he was one of those who rendered valuable assistance to the speaker in carrying out a large enterprise a number of years ago, and we have adopted his facts, and for convenience have used some of his methods, but have been obliged to entirely disagree with his conclusions. For instance, we calculate that the cost of the steam and electric generating plants will be about three times as much as he states, the transmission plant and sub-stations about twice as much, and the operating expenses about 5½ times as much as he provides for. Necessarily the conclusions are diametrically opposite.

The calculations are based on the operating expenses of a railway system, comprising nearly 2,700 miles of road and employing 1,800 locomotives. By calculations based on the train miles, checked by the reported coal burned and the probable number of engines in use, Mr. Baxter ingeniously determines an average of 140,000 horse-power, considered as continuously operated, which, in our calculations, we estimate will require to replace it 280,000 H.P. in the stations, on the basis of 50 per cent. efficiency from stationary engine pistons to track, and if 60 per cent. can be obtained by commuted fields, or other means herein discussed, the difference simply provides for an expected increase of travel. From the probable average power and the actual reported operating expenses corresponding thereto we proceed as follows: For facility of calculation and to obtain an underestimate, rather than one too large, the power required for the switching engines is distributed among the regular trains on the road. It is also assumed that the average number of trains is continued the entire length of the road instead of using a much greater number than the average for suburban travel. These methods cause an underestimate of the cost of the electric transmission, but enable the cost of operation to be accurately worked up from the averages. The latter is the more important point, as the other merely involves comparatively small questions of difference in the amount of interest. By this generalization the trains will be assumed as separated about 7½ miles, independent of direction, over the whole length of the road for every hour in the year. On this basis there will be required on the average, 106 station

horse-power per mile of road, independent of direction of trains, but to provide for concentrations which will inevitably occur, the generating plants and transmission lines have been worked out on the basis of 150 H.P. per mile. The assumed number of trains will require on the average about 400 H.P. each at track, or 800 at station, which is high for an average, as the power of the switching engines is, as explained, distributed along the whole line for convenience of calculation on the basis of averages. To obtain the economy due to fairly large stations they are assumed to be separated 45 miles from each other, and at two intermediate points transformers and rotary converters (transformers) located, by which means the feeders are supplied every 15 miles. On the above basis it is assumed that 6,750 H.P. is installed at each steam station, and 2,250 H.P. at each sub-station. To avoid overestimates the cost per H.P. of steam and electric plant in main stations has been assumed as only $80 per H.P. with $20,000 for buildings, and for the whole apparatus in the sub-stations there has been allowed only $10 per horse-power and $10,200 for buildings and the copper in the high tension lines. The low tension copper has been worked out on the basis that half way between the main and sub-station two trains may meet, each requiring 1,000 H.P., and that a uniform section of copper sufficient to carry 7½ miles, the current required for half of this power, at an original tension of 700 volts and a drop of 20 per cent., would be ample for the whole length of the low tension lines. On this basis the cost for copper at 13 cents per pound for the outgoing low tension conductors will be $12,386 per mile. It is assumed that provision for supporting the outgoing conductors and the bonds in main track for return current will cost $5,000 per mile. On the basis of these prices, without considering incidentals, the total cost of the electrical generating and transmission plant foots up $31,057 per mile, the annual interest on which at 5 per cent. is $1,553 per mile. If the services of the 1,800 steam locomotives can be furnished by 1,500 new electric locomotives at $10,000 each, the same will cost $5,556 per mile, requiring $278 annual interest per mile, making the total interest on steam and electrical plants, including locomotives, $1,831 per mile. The operating expenses of the station considered as a steam station only, from Emery's tables reduced to 24 hours and 365 days, modifying cost of plant and eliminating coal and interest, is found to be $25.54 per average H.P. per year. The time of 12 extra men for care of electric apparatus in the main and two sub-stations amounts to $2.75 per H.P. per year, which makes the total operating expenses of the generating, transmission and locomotive plants, exclusive of coal and interest, $28.59 per average main station H.P. per year, or $3,031 per mile, or with interest added, viz.: $1,831 as above, a total of $4,862 per mile. The operating expenses of the station thus calculated include an allowance for repairs, insurance, taxes and renewals. It

should be recollected that the cost of coal has been already provided for in the percentage of saving first developed, and that the train expenses are assumed to be the same as for steam locomotives. The operating expenses of the road using steam, amounted to $15,187 per mile. Of this, as previously stated, 6.56 per cent. will be saved by the use of electricity, corresponding to $996 per mile. This subtracted from $4,862 per mile (given as the cost of operating expenses of the generating stations, etc., with interest added), leaves $3,866 per mile per year as the additional expense which will be entailed by the application of electricity as a substitute for steam; so, on the basis that the operating expenses are 50 per cent. of the gross receipts, such gross receipts must be increased 12¼ per cent. by the introduction of electricity over the whole length of the line, in order to enable the road to pay the same dividends as before.

It may be considered that the results will be changed materially by the use of high-tension transmission throughout. If tri-phase currents at a tension of 10,000 volts were received by each electrical locomotive, the tension reduced by transformers carried by the locomotive, and current employed to operate induction motors directly, or to operate direct current motors through rotary converters also carried by the locomotives, the saving independent of extra transformers and converters would amount to $9,714 per mile, corresponding to $486 interest per mile, and reduce the total increased operating expenses to $3,380 per mile, which would require that the gross receipts be increased 10.2 per cent. in order to pay the same dividend as before, instead of 12¼ per cent., for combined high and low tension transmission. The saving in dollars is quite large, but the total costs are so enormous that the saving makes but a small difference in percentage. It will similarly be seen that differences in kind of apparatus employed will have very little difference on the general results, though the savings are important in themselves.

It must be recollected that these results are based on providing electric traction for the whole length of a trunk line. It can hardly be expected that the gross receipts for the whole line will be increased, say, one-eighth by such an application. If, however, the application be made within the radius of suburban traffic such an increase is not only probable, but it may be expected that the cost of operation per passenger mile will be reduced in greater proportion than stated, so that the application of electric traction will pay from the outset. These considerations will apply to longer distances on railroads like the New York, New Haven and Hartford, where the passenger business furnishes the larger proportion of the income.

Again, it is possible to accomplish with the electric locomotive results that are impossible with the steam locomotive. The power for the former being generated originally in stationary

boilers, or in some localities derived from waterfalls, is not limited, and the power of the motor can be increased indefinitely, so that in particular locations a demand either for greater power to obtain more speed, or a greater or more continued tractive force than is now possible with a steam locomotive, can be met by electricity without difficulty.

On the whole, therefore, although the application to the whole length of long trunk lines does not seem practicable under present conditions, there is no doubt but that the industry will grow in the future as certainly as in the past.

Mr. Charles K. Stearns (*communicated*):—The information obtained from the operation of the Nantasket electrical line, during the summer of 1895, was more or less of a general nature, as the chief object in view from the standpoint of the railroad officials was to demonstrate that an electrically equipped road could be operated as satisfactorily in regard to the facility of handling large numbers of passengers on time, as a steam road.

This point was proven beyond doubt, as the railroad officials have expressed themselves as satisfied, after observing the ease with which the trains carried the large number of people the boat line brought to the trains at Pemberton, the extreme end of the line.

The cost of operating this line during its first season was roughly obtained, but the experimental nature of the car equipments was such as to render any figures as to the cost per train mile anything but accurate.

The equipment in the station is no doubt well known; suffice it to say, that there were installed two 500 K.W. direct connected generators wound for 600 volts potential; two compound condensing Green engines of about 1,000 H.P. capacity each, and eight return flue boilers, 18′ x 72″ diameter.

The train schedule of July, 1895, called for 150 trains per week day, or an average of 148.1 trains per day, including Sundays, and in 1896, 66 trains per day, or, including Sundays, an average of 68 trains per day. In 1895 these trains consisted of a sufficient number of cars to accommodate the people, but in 1896 the trains were limited to 2 cars, a motor car and trailer. To accommodate the passenger traffic, extra trains were made up and run between the regular scheduled trains. A fair average on Sundays would be about 150 trains, and week days 75 trains per day. This partially accounts for the difference in the coal consumption in 1895 and 1896, although in 1896 the engines were run condensing, while in 1895, non-condensing.

The line operated in 1895 was 6.86 miles of double track, equipped with special trolley wire, and in 1896 the same length of trolley line, with the addition of 3.64 miles of double track equipped with the third rail. The actual rail laid is about 3 miles double track, allowing for omissions of the rail at the

crossings and stations. The distance from the power station to the end of the third rail is 4.75 miles, and to the end of the trolley line 5.75 miles.

The following table, although incomplete, gives some idea of the operation of the power station during July, 1895 and 1896:

	July, 1895.	July, 1896.
Hours run	605½	546½
[1]Ave. Elec. H.P. per hour	245	349 1/16
Lbs. coal burned	629,575	571,100
Coal per E.H.P. hour	4.24	2.99
Ave. trains per day	148.1	68
Ave. cars per train	2.1	2
Maximum cars per train	7	2
Train miles	32,803	44,173
Passengers	267,143	
Tons passengers	18,700	
Tons, dead load	162,089	
Tons total load	180,789	
Per cent. paying load to dead load	10.2	

In regard to the third rail equipment: It must be remembered that this was in the nature of an experiment, and several defects have been noted, which no doubt will be corrected in the future.

The rail itself is about 100 lbs. section, rolled in the form of an angle of 110 degrees, with a standard rail top or surface for the shoe. This rail, as originally installed, was bonded with cast copper bonds, and further supported by insulating blocks placed 7½′ from each end. This was found insufficient, and fish plates were put in with a flexible copper bond and the rail supported by insulating blocks placed as near the ends as possible, with an additional block in the centre to prevent vibration. These blocks are about 6″ high, and fit the angle of the rail. This rail is not continuous, the grade crossings, of which there are several, being omitted, and the train running by momentum over them. This was necessary, as the width of some of these crossings is considerably greater than the length of the motor car. At the stations, also, the third rail is omitted and the overhead wire used. The installation consists, therefore, of a combination of third rail and overhead wire, the train starting out of the stations by the overhead wire and trolley, and running between stations by the third rail and shoe.

I cannot say that this plan is very satisfactory, particularly at night, when the different crossings are emphasized by darkness in the cars. The third rail, as now laid, is alive the entire length.

It seems to me a question as to the advisability of operating a line with a 500-volt difference of potential in a position where there is liability of careless persons coming in contact with it. One accident has occurred and, although I understand legally,

1. During July, 1895, power was furnished by the station to operate the Hull Street Railway, the average of which was 30 H.P. by separate wattmeter. Consequently, the average power for the railroad was 215 H.P. 349 H.P in 1896 includes about 40 H.P furnished the Braintree & Weymouth Street Railway, so that the power for the railroad amounts to 309 H.P.

the public are not allowed on the right-of-way, the liability occurs of careless parties or workmen coming in contact with the two rails.

The regular steam rail used is 6″ high. The third rail is 7″ from the tie. This allows a clearance of 2½″ from the pilot of a regular locomotive, provided this pilot is up to standard. There have been several cases where a locomotive pilot, chain or brake-rod on a steam train running over the third rail section, has come in contact with the third rail and caused a short-circuit of such length that it was found impossible to keep the current on this section of the electric branch. This section, I will state, is connected with the power station switchboard by a separate feeder and circuit breaker. In these cases the electric trains have come to a stand-still until the steam train was off the section.

From these considerations it seems advisable to adopt a system where the conductor, if of the third rail type, is alive only at points where it is actually used, or at least divide the line into blocks, so that one train will be in a block at a time.

The insulation resistance of the pole line in 1895 was 140 ohms, or an average leakage of 4.7 amperes. This is on a line consisting of 577 Georgia pine poles, the trolley wire being fastened to angle iron cross-arms, which are bolted to the poles by two ⅝″ through bolts. No insulators are used. On the third rail there are about 3,500 points of support. I am sorry to say that I have been unable to obtain information as to the leakage on the third rail under varying weather conditions.

A serious objection to the present installation of the third rail is the connection by lead covered cables between the ends of the rails at crossings and stations. The surface leakage from the rail to the lead covering must be considerable, although I am not aware as to whether it has been measured or not. The outside covering of the cables has been found to be very sensibly alive.

Aside from the use of the third rail or trolley wire I believe that more uniformity of load in the station should be obtained by the use of storage batteries either on the cars or in the station. The extreme demands for power on the line, when 75 trains were in service, and these trains heavy, were very noticeable compared with the service of 150 trains per day in July, 1895.

In conclusion, it seems very desirable to put in a third rail in preference to the overhead trolley wire in such a manner as to avoid any liability of injury from accidental contact with the rail. In other words, put in the rail in blocks and then only such part as is in actual use to be active. A method of this kind would reduce the leakage to a minimum and place the electric road on an equal footing with the present block system of steam railroading.

Mr. Charles H. Davis (*communicated*):—The subject of "Electric Traction Under Steam Railway Conditions" can be divided into a consideration of:—

1. *New Roads* to be built.

2. *Old Steam Roads* to be partially or entirely changed over.

The relative merits of the use of "Electric Traction" or "Steam Locomotive Traction" in each of the above cases may be considered under the heads:—

First Cost.

Total Expenses { 1. Fixed Charges. 2. Maintenance. 3. Operating Expenses.

Gross Receipts.

1. New Roads to be Built.

First Cost.—The cost of right-of-way, stations, terminals, fencing, grading, ballasting and track, will be approximately the same in either system. Overhead line work, or third rail and feeder system, including track, ground and feeder returns, are not required for steam traction and their cost is an additional charge against electric traction. The cost of equipment, excluding locomotive, is in favor of steam traction, as roughly it may be considered that the motors and controlling devices, or the electric locomotive are the items making up the increase in first cost of electric traction. In the first cost of power plants we can assume buildings to be nearly the same—several round houses as against fewer power houses. The steam and electrical plants, including foundations and stack, will not only exceed the cost of locomotives and tenders per horse-power, but in the use of central electric stations a greater amount of horse-power must be installed. This is especially so when lines are very long, making it necessary to duplicate the central station, or use sub-stations, or both, before it becomes necessary to duplicate locomotives by changing them. Should the headway of trains and their weight and capacity become similar to street railway practice in large cities, then, and only then, would electric power be less in first cost than steam locomotives; if the total power required were large, this might even result in lower first cost of the entire system.

No attempt has been made to give figures, as each individual case must be studied and the difference in first cost determined; but it will in general result in favor of locomotive traction with the exception noted.

Total Expenses.—1. Fixed Charges:—These will be greater for electric traction owing to greater first cost, except in the one case mentioned above.

2. Maintenance:—This subject is too wide to be fully discussed here; but it can be assumed that permanent way, track, car bodies, trucks and other items, the same in each case, would be maintained at equal cost. It is probable that the cost of maintaining the power plant, motors, line, etc., of electric traction would exceed the cost of maintaining locomotives, tenders, etc., and that the saving due to less wear and tear on track and roll-

ing stock in electric traction would not make up for the difference. The liability to break-downs in electrical apparatus is greater than in steam mechanisms, thus tending to increase cost of electric traction, not only on the line, but in the power house. Should the headway be decreased, as already suggested, the comparative cost of maintenance of electric traction would decrease, resulting in favor of such traction, although it may be hard to determine the line at which the saving over locomotive traction will take place.

3. Operating Expenses:—Administrative, legal and extraordinary expenses can be considered the same; train attendance the same, except in the case of close headway and the use of motors under each car, in which case electric traction shows a decided saving. Terminal, station, signal and telegraph expenses can be considered alike in each case. The cost of coal would depend largely upon the amount of power necessary to operate a given road: for the larger the power and more frequent the trains the greater the saving by the use of electric traction. Many central stations assumed to produce a horse-power at lower cost than by smaller units really do not, mainly due to the fact that so large a part of such a station is idle many hours of the day, and, although at their maximum point of economy, they are far ahead of small units, the question at issue is not "the cost of a horse-power at the station," but "the cost of a horse-power at the rim of the driving wheels." The cost of this last mentioned horse-power for electric traction is not only made up of station expenses, but also line expenses and electrical equipment expenses, when compared to the cost of the same horse-power produced by a steam locomotive. When these facts are taken into consideration, it is invariably found that the controlling factor is the headway of trains; the less the headway the more surely will it pay to use electric traction, and vice versa so far as the cost of a horse-power at the rim of the driving wheel is concerned.

A general conclusion would be that the question of total expenses depends so largely upon each individual case that only a study of it will enable one to arrive at a reliable result; but that with light weights, small capacity and frequent service, electric traction can be operated more cheaply than locomotive traction.

Gross Receipts.—The question whether the gross receipts of a given road will be affected by the use of one or the other power under discussion is a most interesting one. Experience shows that where an electric road has paralleled a steam road it has taken most of the latter's business at first, but less as time went on; and that it created a demand for intercommunication which had never existed before—the bulk of the passenger travel coming from this cause. This is interestingly shown in the arguments of Judge Hall (Vice-President N. Y., N. H. & H. R. R.) and Judge Gager, of Connecticut, before the Legislature of the State at its last session. This, of course, refers to passenger re-

ceipts only. Freight receipts would not be affected by the use of one power or the other, they increasing only as the country grows and rates fall, together with better facilities. Receipts from express and mails might be materially increased by the use of electric traction when giving more frequent service. It appears that the close headway and "leave at your door" service of electric roads are the main reasons for their induced travel. The question of how much more the travel would be increased by the use of electric traction and frequent service is problematical, for the "leave at your door" service is wanting in steam railways as they are, but why not change them? If this could be done, past experience and data would give a good basis from which to estimate future results.

The conclusions one arrives at is that for long lines, infrequent service, where freight is a large proportion of the business, and where centres of population are far apart, the steam locomotive is the only paying method of to-day, as the first cost will be less, as well as total expenses. The writer has had several opportunities of determining these facts. What development may bring to electric traction in the far future cannot be foretold.

2. Old Steam Roads to be Partially or Entirely Changed Over.

First Cost.—What has been said under "new roads" will apply, with the additional disadvantage in the use of electric traction due to the increased first cost arising from the necessity of throwing away old steam equipment, either in part or whole. In some cases this would be unnecessary, as with large systems, where existing equipment could be used on that part where electricity did not replace steam locomotives.

Total Expenses.—Remarks under "new roads" will apply; and it would, therefore, appear that unless steam railways can change the character of their service to more nearly conform to street railway practice, they will be in many cases unable to adopt electric traction in place of steam locomotives to their own profit.

Gross Receipts.—What has been said under "new roads" again applies; therefore existing steam roads, to increase their gross receipts, must give quicker and more frequent service, and must give as near as possible the "leave at your door" service.

Conclusions.—The writer believes that electric traction will be profitable to steam railway systems when some or all of the following conditions are fulfilled, depending upon the special problem to be solved:—

1. Steam railway managers must avoid making the mistake which took place in the change from horse traction to electric traction, namely, of trying to reduce the first cost of changing by the use of old methods, material and equipment, which, although entirely suited to the old system, proved most unsuitable under

the new conditions. The tendency is to repeat this mistake, and too much stress cannot be laid upon avoiding it. The old equipment partly made over, the old method of operating, etc., will not bring success in the use of electric traction; and if followed from necessity, would indicate the strongest argument against the change.

2. Long distance, heavy trains and infrequent service, if a necessity, will prevent electric traction being profitable. Therefore, where gross receipts can be increased by light trains and frequent service, thus decreasing expenses as compared to steam locomotives, electric traction will prove profitable. One of the best examples of how this could be applied is found in the suburban service of the Pennsylvania Railroad out of Philadelphia. It is, of course, understood that electric cars can be operated over the same tracks as trains drawn by steam locomotives. A change of system requiring more frequent service for success might necessitate one or more additional tracks, which, in some cases, would delay the time when a change would be advisable.

3. Steam railways, where the second condition is fulfilled, can better the results where they operate part of the system on the "leave at your door" plan. This suggestion may seem to some a radical departure, but I commend it to the careful thought of those interested.

Mr. H. Ward Leonard:—Mr. President and gentlemen, I have made no preparation, and hence have no remarks to make which are very well defined. There is one point that has occurred to me in connection with the remarks of Dr. Emery that I think worthy of comment, although they embraced so many figures it is impossible to speak conclusively off hand. I noticed that in the cost of conductors for the low tension portion of the system, if I understood him correctly, he allowed $12,000 per mile for the copper, and that the trains were located at about 7½ miles apart, and roughly about 500 horse-power to a train. This, it strikes me, is an overcharge, as regards investment—about $85,000 for copper for a train of 500 horse-power—and naturally will make the cost of investment very large against electric railways. One point that I have always believed in, and that it seems to me is likely to be more and more pronounced in the future, is that there must be a conversion of energy before we can operate the electric locomotive at all, and the question arises as to where such conversion should take place. Of course, if we convert our energy and store it, by the use of storage batteries in the station or along the line or on the locomotive, we are, in one way or another, converting the energy that we are using in the locomotive. If we substitute instead of storage batteries in one place or the other, rotary transformers along the line, we are also converting. In the latter instance we are adding very greatly to the cost of the equipment by the fact that each one of these converters along the line must have capacity not merely for one

train, but for the maximum that may get in that section at one time. What I wish to emphasize as my belief in the matter is that the conversion must take place, for the greatest advantage, upon the locomotive itself; that, if storage batteries are to be used they should be placed upon the locomotive. If rotary transformers are to be used they should be placed upon the locomotive. The transmission of power over considerable distances should be done by the alternating system, to secure the best results as regards economy and flexibility, and especially in the case of long distance work, as regards the convenience of securing a large number of feeding points and thereby reducing the cost of any low tension conductors to a very much lower figure than that given by Dr. Emery.

Now the question arises as to what would be the best method of operating the motors, and I think there can be little question to-day that a continuous current for the motors is preferable to the alternating. If it be true that the alternating should be used for the transmission, and that the continuous current should be used for the propelling motors, and that rotary transformers be upon the locomotive, the cost of conductors then, as regards distribution, is limited only by considerations such as would pertain to any long distance transmission—the possible voltage along the line. The conversion could be as cheaply accomplished on the locomotive as alongside of the road. Each transformer, in a case where the transformer is located on the locomotive, would have to take care only of that particular locomotive and train that it was intended for, and no margin need be provided to take care of additional transformation as would be the case in transformers which were outside of the locomotive itself.

As regards the question of possible methods of gearing, I may say that there is one electric locomotive which has run some 2,000 miles covering distances of five and six hundred miles straightaway, which did not meet with any difficulty of the character described by Dr. Emery as to the methods of gearing and connecting between the locomotive and the axle. This is the Heilmann locomotive, which had, in the locomotive which was tested about two years or more ago, a single reduction between the motor and the driving axle. There were no coupling rods—side rods—on this locomotive. It ran at upwards of sixty miles an hour and no difficulty of the nature spoken of was experienced. But on the contrary the motion of the locomotive was conspicuous by its smoothness and entire freedom from all jar. The Heilmann locomotives which have been under construction since the original tests, and which will be in practical service very shortly, have the axle passing through the centre of the motor; that is, there is no gearing, but the driving is accomplished by the armature being connected to the shaft through a kind of spider—something after the nature of the method of driving which we are familiar with by its use in the Short gearless motor

a few years ago. This method of driving will be soon tested and we shall then be able to learn whether such difficulties as have been pointed out will or will not arise. A thing which I do not think enough stress has been laid on in the comparison, is the fact that we have reached what appears to be practically a limit in the size and horse power of steam locomotives; whereas there is practically no limit, as compared to the present limit, in the horse power possible for electric locomotives, and since the thing which is of the greatest importance to-day in railways is to secure, first, higher speeds, and second, greater hauling power, it seems to me that the electric locomotive has a very marked advantage in those lines. Take, for example, the steam locomotive which hauls the New York Central "limited" and which has been pretty carefully tested between here and Albany. The maximum horse power was in the neighborhood of a thousand. The horse power that was developed while accelerating the locomotive to its full speed, and while the speed was at the rate of about thirty odd miles an hour was about 600 horse power. The steam pressure fell very rapidly as the speed increased, that is to say, the mean effective pressure in the cylinder; and this is a trouble which is met with in steam locomotives which will be absent in the electric locomotive. There is a very marked falling off in drawbar pull due to the inability of maintaining a high mean effective pressure in the cylinder of the steam locomotive which would require considerable modification from present types before it can be avoided, it being due to the limitation of rapidity of admission of the steam and one or two other considerations. The maximum weight on drivers that steam locomotives have, is of course the limit to their hauling power, and that very rarely exceeds about 170,000 pounds, and with the electric locomotive there would be no difficulty in making that weight almost anything desired. In the Heilmann locomotives that are now under construction that weight will be 230,000, and that 230,000 pounds will be effective for a perfectly smooth pull. Tests that were made upon the Heilmann locomotive in comparison with the steam locomotive by means of a dynamometer car showed a very marked difference in the smoothness of the drawbar pull. The curve of the electric locomotive as might be expected, was quite smooth, while that of the steam locomotive was very jagged. All this of course is very influential with a very large load behind, in tending to skid the wheels. One good feature of the Heilmann locomotive which ought to commend it, if it has no others as some people seem to think, is that it enables one to study with great accuracy the electric traction problem. The question of speeds and horse power, drawbar pull and all such points as that, can be very accurately studied by means of it. The cost of a locomotive of that type is necessarily going to be considerably higher than that of the ordinary steam locomotive. But the hauling capacity is going to be so greatly increased, and also its possible speed, that it may have a field which would not

pertain to it if it had no advantages in speed and hauling power. The Heilmann locomotive is now being finished and will be tested so soon, that a great many of these points will soon be a matter of fact, and we can secure more reliable data of that nature than we have at present. One point which I think is rarely appreciated is this: That tests upon the steam locomotive show that the efficiency between the indicated horse-power in the cylinder and the horse-power at the drawbar, which, of course, is the efficiency of the machine—the ratio between the horse-power at the drawbar and that in the cylinder, for the steam locomotive operating at about sixty miles an hour, is between 42 and 43 per cent., which, I think, will impress you as quite low. The expectation in the case of the Heilmann locomotives, based upon well known features in the Willans engine and in generators and motors, assuming 90 per cent. for the engine and 95 per cent. for the generators, 98 per cent. for the conductors and 90 per cent. for the motors, will give an efficiency at 60 miles per hour of some 47 per cent. as the ratio between drawbar pull and indicated horse-power in the cylinder. I think we must all admit that the question of attempting to replace the steam locomotive of to-day is an extremely difficult task for the electrical engineer. But it does seem to me that we should draw out as many points as we can, favorable to electric locomotives, and it does not seem to me that that has been done in the remarks of Dr. Emery.

Mr. Geo. S. Strong:—Not being a member of the society, I was invited here to-night by the secretary to discuss this matter from the standpoint of a locomotive man. In doing so, I do not want to be understood as being partial to the locomotive. In fact, I am on both sides, as I am interested in the building of power plants for electricity as well as the building of locomotives. I have studied this subject from the beginning of the electrical operation, and as regards the Heilmann locomotive, I might say that I was the first one to build a motor car on the principle of the Heilmann locomotive, and I have had about $20,000 worth of experience in that line. (Laughter.) And as regards the efficiency, I had an electrician who promised me 95 per cent. of the power of the engine which was put on the car. We had a gas engine which indicated and gave a brake horse-power of forty horse-power. The generator was directly on the shaft of the gas engine. The motors were directly under the car with the wire connections very short—not over ten feet of wire in it. I think two mules could have pulled that car faster than that forty horse-power engine could drive it. (Laughter.) Now that is my experience with that kind of a motor. I do not say that that cannot be beaten by a properly constructed generator and a properly constructed electric motor under the car, but it led me to believe that some other method of transmission of power would have to be originated before the gas motor would ever become an efficient motor for driving street cars.

Now, as regards the question of the amount of coal necessary to drive a locomotive, Dr. Emery gives six pounds as the average. Mr. Westinghouse has given it as high as eight pounds. I have tested a number of locomotives that ran as low as three pounds. I have a locomotive to-day built, ready to run, on which I will guarantee to give a horse-power for two pounds of coal. I am ready to undertake to build to-day one locomotive or a hundred locomotives and guarantee a horse-power for two pounds of coal, on the axle or on the drawbar behind the tender.

Now when you come to talk about ordinary locomotive practice and what is possible in locomotive practice, and what has been demonstrated as thoroughly practical in locomotive practice, they are entirely two different things. Only two weeks ago at a meeting of the Railroad Club in this room, this very subject was discussed. A paper by Professor Goss was read on the "Results of High Rates of Combustion in Locomotive Boilers," in which he demonstrated that fully 33 per cent. of the coal in an ordinary locomotive goes out through the stack unconsumed, that is, where the grate area is about 21 feet and where the rate of combustion is rushed up to 225 pounds, as I know on some roads it is the regular practice to-day to burn 225 pounds per square foot of grate area. That is entirely unnecessary, and boilers are running to-day in this country which are giving ten pounds evaporation from a temperature of 212, on a locomotive, and there is no trouble in getting a temperature of 212 on a locomotive. There are abundant ways of using exhaust steam to give it, and it has been demonstrated thoroughly and practically that the water can be heated to that temperature on the engine. It has been demonstrated thoroughly and practically, and locomotives to-day are running in regular service that are giving a horse-power on 20 pounds of water—regular work, every day in the week right along. Twenty pounds of water on compound locomotives is not out of the way, and it can be reduced down to 17 and 18 pounds. Now our friend here gives us for this branch of the consolidated road, 2.95 as regular consumption for electrical horse-power in the station. Now, that is with one of the best engines—you know the Green engine. That is one of the best engines there is in the market to-day. You cannot beat it very much when it comes to giving the greatest efficiency for a given steam pressure. Now we all know Dr. Emery states in his paper that we cannot expect more than 50 per cent. of that on the axle from the motor after he had gone through all this immense expenditure to get it there, you cannot get more than 50 per cent. on the axle; so that that engine must necessarily have used in the neighborhood of six pounds of coal per horse power developed on the axle on the car. Now to give you an idea of what you have to contend with—I am not saying this to discourage you at all (laughter)—in fact I have been through the mill myself; I know how it is to make inventions and how difficult it is

to introduce an invention after you have demonstrated that it is all right. If I were to go to the New York Central with a bond of a million dollars and offered to save one-half of their coal and give them their locomotives if they would give me one-half the saving for five years, they would not listen to me; they would not listen to anybody else. It would not make a bit of difference. They would say: "If you can give us something cheap, that won't cost anything more than we have got to pay, we will try it; but we won't spend any more money. This coal bill is a thing that is going all the time and might be distributed in dividends, but we won't spend any more money." That is the cry. You cannot go and sell anything that costs any more money than they are paying. They want a cheap thing, and when you come down to getting efficiency, that is something that they don't think very much about. Now to give you an idea of what you have got to contend with in the question of handling trains: One estimate here to-night is 500 horse-power as the average for a train. Now as much as ten years ago I took a locomotive that I built for the Lehigh Valley road out over the western roads. On the Northern Pacific we took a twelve car train from a dead stop 10.8 miles in eleven minutes. I indicated the engine myself. She gave a mean effective pressure in the cylinder of 70 pounds in making 326 revolutions a minute, and indicated 1810 horse-power on 1,848 square feet of heating surface and 60 square feet of grate area, 30 horse-power per square foot of grate area and nearly a horse-power for every square foot of heating surface in the boiler. That engine, on the Fort Wayne road, took a 10-car train from Fort Wayne to Chicago, making 23 stops and five slow-downs. The running time for the whole distance was one mile per minute. She ran from a dead stop to a dead stop and made a crossing stop in eight minutes with that train, which weighed, including the engine, over 500 tons. Now when you have to pick up a load of that kind and run with it and stop again, it requires more power than any electric locomotive could give with the same weight. Talk about the weight on the drivers, that engine had all the weight on the drivers she could utilize, and she gave a drawbar pull of 20,000 pounds. An ordinary train does not require to pull it after it is started more than a 1,000 pounds to the car, so that 20,000 pounds adhesion is all any engine can utilize. She would slip her drivers in starting. But by carefully starting, she has all the adhesion she can utilize. That engine pulled up an 86 foot grade from St. Paul to Minneapolis, a 14-car train of cars that weighed on an average of 85,000 pounds a car. The engine itself and tender weighed 100 tons. Now that was a drawbar pull of 23,500 pounds. I took indicator cards, figured the work done on the drawbar and it was 23,500 pounds pull on the drawbar, which was about one-fourth the weight on the drivers—a little more than one-fourth the weight.

Now as to the question of efficiency. Our friend here has stated that only 45 per cent. efficiency is obtained in regular work. We made a large number of tests extending over a month on the Lehigh Valley road, where we had opportunities, with a dynamometer car, and knowing the grade, to figure the lifting of the engine—lifting a train a certain distance into the air in a given time—where we got a horse-power for 20 pounds of water, by the pull on the drawbar, 20 pounds of water in a horse-power hour. The work done and the efficiency, as far as the friction of the engine—the difference between the friction of the engine and the indicated horse-power would not amount to more than ten per cent. in that work, at a speed of about 30 miles an hour. Now these are only pointers. I have not taken time to go into an elaborate paper. I simply give you a few facts which I have dug out by hard knocks right on the locomotive myself. Now as regards the question of speed and also the question of the even pressure on the rail, I have lately built a locomotive which is so perfectly balanced that at a speed of 75 miles an hour you can read a newspaper in the cab. It rides as easily as a Pullman car, and the pressure is absolutely the same at every part of the revolution. That engine will do its work with the lowest grade of coal that you can buy in the market; it makes no smoke, throws no cinders and makes no sound from the exhaust. Now it meets all the conditions, all the requirements that an electric locomotive could meet. The only advantage that an electric locomotive would have over the ordinary locomotive would be that it would give an even pull on the drawbar, an even pressure on the rail and would not throw any sparks or make any smoke. Now the engine I speak of can be duplicated any number of times for $12,000. She will give 2,000 indicated horse-power. She will take 12 Pullman cars from Philadelphia to Jersey City in 90 minutes. The same engine has taken from Susquehanna to Hornellsville an eight car train, with eight stops and five slow-downs, at an average of 61½ miles an hour for the whole distance. When you undertake to beat that kind of work with an electric locomotive, you have got a big contract.

MR. A. E. KENNELLY:—Mr. Chairman and Gentlemen: This question of applying electric traction to steam roads has been a fascinating subject to many of us for quite a few years, and I do not think the problem has changed very much in its character during the last five or six years, although its limitations become perhaps more clearly visible from year to year. The manifest success which has attended the introduction of electric street cars where comparatively low speeds are necessary, where frequent stops can be made very cheaply, where a car will stop at any person's door or at any street corner, has been so marked, that it has been predicted that the electric locomotive would rapidly transplant and displace the steam locomotive. The conditions are,

however, in this case so widely different that I do not think we can postulate, at first sight, any such conclusion. So soon as you get upon a reserved track, and have to make a high speed, you cannot stop—you have not the time to stop—it costs too much to to stop; then you meet the conditions which are found in existing long distance steam roads to-day. For many years this problem of carrying passengers rapidly and comfortably over great distances has been dealt with by steam locomotive engineers, and the maximum economy has been long striven for, that existing conditions will permit. It is contended that if we could replace the steam locomotives of the present time by electric locomotives that we could economize—that we would show an economy by reason of the saving in fuel. Now I never saw any engine that it was claimed would produce a horse-power on say two pounds of coal per indicated horse-power. I have always understood that it took five and six. I will assume that for the present time they do take five and a half pounds of coal on an average throughout the country. The fuel expenses of the roads throughout the country are stated in the statistics to vary from 7 per cent. to 13 per cent. of the total operating expenses, and we may take an average of say 10 per cent. of the total operating expenses as covering the cost of the coal and perhaps also the cost of the water supply. Assuming that we had some kind friend who would take a steam railroad and give us an electric locomotive tomorrow for each steam locomotive, having the same power and being worth about the same amount of money, and also providing the plant and conductors whereby that system could be operated, we should be able to throw out all the tenders, and that would be a considerable saving, no doubt. We should save 25 tons or so to every train, and that would enable us to haul a larger load of freight and carry perhaps a little higher speed with safety for passenger service. The difference in coal consumed might amount to as much as twelve per cent. upon the passenger trains. It might amount to only three or four per cent. on freight trains. But suppose it averaged about six per cent. We should have a saving of fuel of about 6 per cent. simply by displacing the tenders. The steam plants situated in a central station might possibly, let us say, generate an indicated horse power on two pounds of coal—I fancy that it would be safe to allow three, to meet average conditions of variable loads. With three pounds of coal per H. P. hour at the central station for the transmission system we should probably expect to develop a horse power hour at the shafts of the electric locomotive for about five pounds of coal. We should therefore be very little better off than we are at the present time with good steam locomotives. Even if we succeed in bringing the coal consumption down to two pounds per one H. P. hour, we could not expect to develop a H. P. hour at the locomotive shafts for less than 3¼ lbs. We should, however have a greatly increased plant, a much larger inspection and much

greater fixed charges, and we could not so far as I can see, expect under the conditions of railroad traffic of to-day to see any saving effected.

But the question, fortunately for us, does not lie solely in that compass. Economy is not the sole point of advantage in which we can expect to increase electric traction. If economy were the only factor of passenger transportation, we should never find that the passenger steamers which run across the Atlantic would increase their expenses every year by putting more and more horse power on board their ships consuming coal approximately in proportion to the cube of the velocity, in order to carry their passengers over the ocean in a few hours less time. And if it can be demonstrated that an electric locomotive can safely carry passengers at say 100 or 120 miles per hour, I think there is a very large field open for the electric locomotive on the lines of high speed. It may cost more, but it is very probable that people would be ready to spend more for high speed passenger service. The conditions at such speed would be so radically different, the problem presented would be so different, the number of cars per train and the character and style of the cars so different that a new problem is presented, and on those lines I think there is a future for the electric motor. But on the lines of the present steam locomotive and the mere substitution of electricity for steam, I do not see where we can claim an advantage. The schedule time which the steam railroad time tables of the last twenty years show us, do indicate an improvement in express train speed, but by no means a marked improvement. I think that is a tacit admission to the effect that the steam locomotive cannot commercially be made to run on existing railroads at very much higher speeds than that attained to-day. How far that may be due to imperfection in the locomotive as a machine, or how far to imperfections in existing track is a more difficult question. But if, as we believe, an electric motor can be produced, making up in lightness what it lacks in drawbar pull, that will haul light cars at a very high speed, then I think we may safely hope for a great future for the electric passenger long distance railway.

Mr. C. F. Uebelacker:—Aside from the matter of expense —not entirely aside from it, but rather a point which brings the question of electric traction away from the question of expense more or less—is the ultimate capacity of the steam roads for freight traffic. As I have been thinking it over for the last few days it seemed to me of a good deal more importance than we have been realizing. The fact is that three or four years ago—in 1892, when probably we had the heaviest traffic of any time on the steam roads, quite a number of them were operated on the verge of congestion. It was a strain all the time to keep the freight moving, and particularly to keep the fuel which runs our cars here in the East, moving from the West. At that time

some of the gas managers around this portion of the country were looking each day to see where their coal for the next day was. When things get into that condition it has come to a point where we have got to find some method of conveying our energy from the coal fields, if that is where we have got to get it from, to the point where it is consumed, in some more concrete form than by hauling fuel in cars. The actual fact is that on several of our roads the coal and coke carried amount to a little more than fifty per cent. of the total freight tonnage. The removal of a portion of the tonnage would, of course, make room for more manufactured products. I think the feeling amongst all the railroads is that they do not want to spend any more money; they do not want to lay out the enormous investments which would be necessary for them to materially increase their carrying capacity. The terminal facilities particularly are pretty expensive—around the City of New York for instance. I think it is getting narrowed down to a question of what form of transmission we will use in order to get energy from the coal fields (the main sources of power) to the point where manufactures concentrate. We have several before us. We have heard a good deal about compressed air in the last few months. I have been looking it up as carefully as I could, but I cannot find very much data about it. As applied to street railroads, the best I have been able to find was in a letter of Mr. Ira Harris, written to *The Railroad Gazette*, along in October sometime. He concludes that air can be compressed at about six cents per thousand cubic feet of free air, and that it is going to take to run an ordinary street car about 417 cubic feet of free air per mile at the speed we ordinarily run. That looked to me very much like about two and one-half cents a car mile for power, and I do not think we are prepared to take power at that rate just at present. I think a fair average for electric work would be about a cent a mile. That is what it costs our road—a little under perhaps. I think the conclusion so far as compressed air is concerned, would be obvious under those conditions. We have the explosion motor of various kinds and descriptions, but there does not seem to have been enough progress made in that to tell what the outcome would be if it was put in large units. Probably the most promising thing is the gas motor, and the distribution of gas for power purposes through a piping system. The piping system is not a thing that we look on with very much favor as compared to a copper circuit—rather more trouble to keep in shape. If, then, we come down to the question of transmission of the energy to the manufacturing centres from the coal fields by electricity, it would naturally follow that the roads carrying the freight between those centres would adopt that power too, and it would come down more to a question of what variation we would have to make in our present practice to adapt that power to long hauls. The first thing that would strike us is that we could not very well go

at it in the hammer and tongs manner that we do in electric railroading. That is, we cannot put in power enough to start the whole road at once, if necessary. It is altogether too large a problem. The excess of power we would have to provide would run into too big a figure altogether—both the excess capacity of the line and the excess capacity in the power-house. The only way in which we can overcome that at present is by the use of the storage battery. Of course, the nearer we get to the point where the power is actually used. with the storage battery, the more we save in the capacity of the line and the station. Putting the battery on the locomotive itself we save in the capacity of station and line both, and approximate very nearly the ideal line. At the same time we cut down the enormous fluctuations which would result from the use of electric locomotives on a line where no such provision is made. Let us try to imagine once the conditions which would exist without such provision for fluctuations, if we have, say, five or six switching engines in the yard moving around at once, and perhaps the Chicago Limited moving out and getting up speed as fast as possible, and four or five locals pulling out of the train sheds. It would take about a 6,000 horse-power plant, and altogether it would make fluctuations from about ten units that the load of that plant would be depending on. They would be accelerating, shutting off and accelerating again, continually. It strikes me that the ammeter would want to give up its job in disgust; in fact, an attempt to work with electric power under those conditions I think would be out of the question, and it comes down to the question of a suitable storage battery to be used on the locomotive. The storage battery is more or less of a problem in itself, but the experiments up on the Third Avenue Elevated, I think, will demonstrate what can be done in that direction. The plan they are adopting there, is I believe, that of placing the storage battery on the locomotive, and that, I think, will be the solution when we come to require a solution of the question.

Mr. Elias E. Ries:—I have listened with a great deal of interest to the discussion this evening. I came too late to hear the first part of Dr. Emery's paper, but it seems to me that this whole question of Electric Traction Under Steam Railroad Conditions might be resolved into three divisions and be considered under three distinct and separate heads. First, we must consider the general question of feasibility, practicability, and economy, in substituting electric locomotives for steam locomotives as such. That point I think has been already demonstrated.

We know that electric locomotives of very large size and power are practicable. The best evidence of that fact is that there are to-day in Baltimore electric locomotives of 95 tons weight which are hauling the heaviest kind of steam railroad trains, including the steam locomotives attached thereto, through the B. & O. R. R.

tunnel, day after day. They are, in fact, developing an amount of tractive power of which steam locomotives of the same weight are incapable; so that the question of *feasibility* of electric locomotion under even the severest steam railway conditions is definitely assured.

The question as to whether or not the substitution of electricity for steam is at present *economical* depends entirely upon the length and character of the railway, its location and upon the nature of its traffic. We must accordingly, before we give an answer to this question, classify these steam railroads, and proceed to consider their operating conditions under the two additional heads alluded to, the first relating to such conditions as are found, for example, on comparatively short interurban railroads, or still better, on the New York elevated railways, where the trains move at close headway, where they are comparatively light, where the structure itself is reasonably short—being less than 10 miles in length—and where all the conditions approximate that ideal which electricians look upon as the best and most economical for a railway service in which the motive power is derived from fixed stations; that is to say, a system in which the train units are short, frequent, light, close together, and in brief, a system in which the load is subdivided and, as nearly as practicable, distributed evenly and smoothly over the entire line. That condition, I think, is fulfilled very closely by the elevated railway systems of this city, and I believe all things considered, that the substitution of electricity for steam locomotives ought to commence right here under such conditions as those. I am of the decided opinion that the arguments against the substitution of electric locomotion for steam on ordinary trunk lines, which have been brought out to-night by our steam railroad friends, would not apply to conditions of the kind that are met with on roads like the elevated or on any reasonably short interurban passenger railroad.

Coming now to the third division or heading, which relates to and includes the long distance or trunk line roads, I may say that we are not at present, *generally speaking*, in a condition to compete commercially with the steam locomotive. Although speculations as to the ultimate use of electricity on long distance steam railroads have been quite frequent, these have never as yet amounted to anything in a tangible way. The steam locomotive is admittedly quite inefficient as a power producer, using, as has been said to-night, from five to six pounds of coal per horse power developed, whereas by generating the power at properly equipped central stations, using large, efficient stationary dynamos, and evenly loaded stationary compound-condensing engines and all the modern coal and labor saving appliances, the energy can be produced at two or a fraction over two pounds of coal per horse power, besides effecting a considerable saving in labor. The margin of saving in favor of the stationary plant is too great

to be ignored, where it can be turned to useful account. Yet there are other features which render it impracticable, *under present traffic conditions*, to operate, electrically, even moderately long distance steam railways. In the first place the trains, instead of being reasonably frequent, close and light, are few, far between and excessively heavy. It has always been the aim of steam railroad managers, and not without reason, to crowd as much traffic as possible into as few trains as could be consistently run, with due deference to the cost of additional train service on the one hand and the clamor of the traveling and shipping public for increased facilities on the other, and so long as these conditions last and the trains are made heavy enough and the schedules separated enough, the steam locomotive can undoubtedly do the work more economically. However, I do not believe that the limit of substitution of electricity for steam will have been reached when we equip a system like the elevated roads or like a short surface road connecting two populous cities or towns and doing a very large and frequent local passenger traffic; but am firmly of the opinion that, with the development of higher transmitting electromotive forces and more simple methods of conversion than those which are now practicable to use, we shall be in a position to attack the problem of general electric locomotion on trunk line roads. This will be the case more especially when we have learned how to build our road-beds and track, so as to permit of higher speeds with safety than are possible with steam locomotives. An electrically welded track, free from mechanical joints of the present type, will go far to bring about this condition of perfection and at the same time diminish the transmission losses due to artificial track-bonding that now enter so largely into our calculations on line losses and copper cost. It is not so much a question of cost as of ultimate construction and operating conditions on these roads. The mere question of economy in coal, as has been fully pointed out this evening, does not enter so largely into the results to be obtained as to be the controlling factor. The consumption of coal alone is only a small fraction of the operating expenses of a road at best, and while saving in that respect is very desirable, yet the absence of it would not keep back the introduction of electricity if electricity can show decided advantages over the present method of operating by steam, either in speed, safety, frequency of train service, cleanliness, lessened proportion of dead load of locomotive and train to passengers, improved methods of lighting, heating and braking, enhanced facilities for handling and dispatching trains, general attractiveness to passengers, or in any other way.

Mr. Kennelly has well said that the transatlantic steamship companies have found high speeds to pay even at the expense of the well known enormously disproportional increase in coal consumption. We can readily save *one-half* of the total coal consumed per hour by our modern transatlantic liners by running

at a speed only a few knots less; or, if we desire to economize still further, we can dispense with coal altogether and cross the ocean under sail, as our grandfathers did before us!

If electric energy generated at power stations is ever to be applied to steam railroad work for long distances, and of this I have no doubt whatever, it is, I believe, necessary that such a sytems shall use high tension alternating transmitting currents, converted at points along the line of way into safe lower-tension operating currents, either alternating or direct, preferably the former, and fed to the locomotives in this converted or lower-tension form, as I stated in the course of my remarks at the last meeting of the INSTITUTE. The introduction of electricity upon steam railroads will bring about new traffic, operating and economic conditions that are now scarcely dreamed of, and upon these conditions its superiority and commercial success will depend.

There is, to my mind, no form of energy yet discovered that is so safe, flexible and economical and so well adapted for purposes of transmission as electricity, whether it be used for railway or other work. It has, like any other method of power transmission, its limitations; but these limitations are by no means as restricted as in the case of other well known transmission methods with which we are familiar. Nor is there, so far as I am aware, any available form of *stored or portable* energy that is at all comparable, weight for weight or bulk for bulk, with the mechanical energy latent in coal, which latter is now used as the source of motive power on steam locomotives, and we cannot accordingly hope for much improvement in this respect. This coal constitutes, with the necessary water, tanks and converting plant not directly required for tractive weight, a very large percentage of the dead load to be hauled over the entire road, and contributes largely to the expense of starting, running and stopping the train. If, therefore, any advocate of portable or stored energy in the shape of coal, gas or petroleum, or some peculiar form of chemical energy, or any other primary generating agent, or the discoverer of more efficient methods of converting the stored energy of coal into mechanical energy, were to come to me with claims as to any special merits or utility it may have over existing methods as a source of power for railway locomotion, I should, in all probability, advise him, if the conditions were at all favorable, to convert his power into the form of electrical energy at a fixed station and transmit it over a small and flexible wire to the cars in the form of current, rather than attempt to carry and transform it into motive power upon the train. If the amount of traffic on any given steam road can be made sufficient to justify the entire equipment of a long distance line electrically, the transmission distance can be easily confined within its economical limits by a proper location of generating stations. In the meantime, there is no reason why portions of the lines on which a reasonably continuous passenger service is

handled or can be developed, should not be electrically equipped, subsequently extending the electric service to other trains and thus gradually displacing the steam locomotives. What we need above all for trunk line roads is a sufficiently high transmitting electromotive force and the most simple and efficient type of converters and motors. This much provided, the remainder will come of itself.

I will now return again to the conditions as they exist upon the New York elevated railway system. There we find that the location is excellent for the economical generation of power near the water front, which extends practically parallel along the whole length of the line and but a short distance from it, and it would be a simple matter to put up two or more generating stations for supplying the line. That condition is better than would exist in the case of most long distance steam roads where facilities for the economical generation of power could not be so readily had. In addition we have the advantage of the short length of transmission, which renders it unnecessary to use alternating or converted currents of any type. With a proper proportioning of the stations, it seems to me that a direct current which is fed to the working conductor at net electromotive force not greater than 600 volts, would do the work; and in that connection it seems to me, after carefully considering the situation and conditions, that in order to get the best and most economical results on a road such as the New York elevated railway system, it would be desirable to supplement the direct line distribution by means of secondary batteries of comparatively moderate capacity carried permanently on the locomotives of the trains. At a meeting of the AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS, held as long ago as October 9, 1888, at which meeting I had the honor of being called upon to open the discussion, I had the pleasure of describing briefly a combined system of this kind for the first time, which events since then have proven to be founded upon the correct principles.

This auxiliary battery is preferably to be carried on the motor car, which is of the regulation passenger length and may be used as a smoking car, and consists of a number of sections which are capable of being connected or grouped in series or parallel by means of a simple controller switch. The battery sections are normally grouped in series with each other but connected in parallel with the motors and across the line, when the motors are being supplied with propelling current from the line, so as to produce a uniform load upon the power station and take care of the traffic at congested points or points that are likely to be congested in the normal operation of the road, by maintaining the working potential constant at distant portions of the line that may be subjected to a temporary overload, and by supplying automatically any sudden increased demand made by the motors. These batteries, however, would not be used in that sense entirely, but their importance is far more wide-reaching, as we shall presently see.

There is a great deal of energy lost on the elevated railway system, for example, in descending grades and in coming to a stop at stations, the stops being exceedingly frequent. The grades there are much steeper and more numerous, and the requirements of rapid transit demand more rapid acceleration with quick but gradual stops, than in the case of the steam railroads.

Now then, by dispensing with the steam locomotive and substituting a locomotive which we will say consists of one motor car for the train, the motor car may take the place of the present leading car so as to avoid increasing the length of the station platforms. This motor-car we will assume is provided with four motors placed below the car floor and each geared to its own axle so as to give a distributed tractive effect due to eight driving wheels, the force of which is, of course, supplemented by the weight of the auxiliary battery, which may be readily placed under the seats along the side of the car or carried upon the truck.

The total number of battery cells to each train would be slightly over one-half of the number of volts on the line, and the cells we will assume are divided into four groups or sections and capable of being connected in series or parallel by means of a special controlling switch used in the ordinary operation of the train. Now then, when a train is descending a grade or coming to a stop at stations and the current is therefore no longer needed for its propulsion, the connection between the line and the locomotive is interrupted by moving the controller switch, which operation converts the motors into braking generators and also connects the battery sections in multiple series or parallel with the motor circuit in such a way as to cause the battery to oppose *a low counter-electromotive force* to the charging current, thereby enabling the mechanical energy or momentum of the train to be converted into electrical energy almost to the point of stopping, which energy is absorbed by the battery to be given out again by it in the form of useful power whenever required! It has been estimated that, of the total amount of energy developed by the steam locomotives on the Third Avenue elevated railway, 59 per cent. of the power expended on a round trip is used in starting, 24 per cent. in lifting, and only 17 per cent. in traction! That means that 83 per cent. of the total power expended upon the elevated railway system in this city is consumed on account of stoppages and grades, of which nothing is recovered, but on the contrary, the waste is augmented by the further use of steam to apply the brakes. If we can reclaim only one-half, or 50 per cent., of this wasted energy by the method described, which I believe by this plan is entirely within the range of practice, it would produce a very great saving in power that could not be accomplished in any other way, and in this manner we would get the benefit, by very simple and reliable means, of the most economic method of operating these roads that to my mind, can possibly be conceived of.

Although the cells of the battery are just sufficient in number to develop the normal line electro-motive force when the sections are connected in series, their size or current-capacity, and consequently their weight, as compared with an ordinary secondary battery car equipment, need be but moderate because of the almost constant accession of charging current and the comparatively limited supply of stored power which this system would require, whether for the maintenance of a uniform station load and equalization of working potential over the entire system, or for emergency use. The storage battery to-day is a far more perfect and reliable affair than it was eight or ten years ago, and as cells are now made that are capable of standing a heavy emergency discharge without injury, it is entirely practicable to equip the motor-car with reasonably light weight cells having a capacity sufficient, if need be, to not only permit the train to make a complete round trip under full load without any aid whatever from the power stations, so as to keep the line going in case of any accident or temporary shut down at the power house, but also to take *entire* care of its own train for shorter periods on certain sections of the line during the hours of heaviest traffic. The battery in such case will have been previously charged during the hours of light travel, while grouped in series and connected across the line in parallel with the motors during the usual operation of the train, or, in the case of "extra" trains, during the time the latter are at rest. This charging process just referred to, relates entirely to the "main" charging in cases where it is desirable to run certain trains during busy hours entirely or almost entirely by their own battery power, as on branches or portions of the line remote from the power station, or on the middle express service tracks (which latter in the case under consideration, it might be desirable to leave unequipped with supply conductors because of the frequent occurence of switches, crossovers, and turnouts,) on which few or no stops are made after the train is once under way. In fact, all batteries intended for such service would receive their "main" charge during the intervals of light travel, while these as well as all the other batteries on the line would receive their normal or "maintenance" charge automatically, according to circumstances, from the line or from the motors when the latter are acting as braking generators as I have already described. Any overcharge of the battery occurring under the last named condition, such as might take place on a long down grade, during which the acquired speed of the train is checked or maintained constant by the conversion of its surplus energy into stored electrical power, is of an advantage in that it is practically given back to the line when the battery is again connected in series, which battery will for the time being act much in the same manner as a booster to the line and its feeders until it has again reached its normal charged condition. In other words, the batteries when arranged as I have pointed out will not

only conserve the energy that is now so largely wasted in the operation of the elevated railways by steam or even by any ordinary direct electrical method, but, by continually and automatically giving and taking energy, they ensure a steady and uniform electrical pressure over the whole line and relieve the machinery at the power station from injurious, unequal and fluctuating loads, permitting of a comparatively small installation that will generate the *average* load continuously under the most efficient and the best possible conditions, a desideratum the importance of which was fully and ably dwelt upon in the inaugural address of Dr. Duncan, delivered before this INSTITUTE last month. For the same reasons, as was also pointed out, the cost of feed wires can be very considerably reduced since they are called upon to carry only the average load, or I may say *less* than the average load, since any sudden or constant increase of current that may be needed is instantly supplied by the battery of the train *at the very point where it is needed* and without any additional loss in transmission, and since a large part, probably one-third, of the total energy required in the operation of the system *is produced and generated upon the train itself*.

The employment of an auxiliary secondary battery upon a car or train in combination with a line conductor, of which I believe I was the originator, having taken out basic patents on this combination and method of operation as far back as 1886, has many important advantages in addition to those mentioned that can only be fully appreciated when it is given a thorough trial on a road such as the one under discussion, where the conditions are particularly favorable to a combined system of this character. Not the least of the advantages is that aside from its regulating, governing and conserving qualities, the battery can be called upon in cases of necessity for a very considerable amount of reserve energy of its own, independent of any aid from the power station or line, a fact that will be appreciated by the management of a railway system which is almost the sole dependence for transit of over half a million passengers daily, the bulk of whom require to be carried in the course of only a few hours. As a matter of fact, all the advantages of both the secondary battery and line conductor systems of operation are obtained by this combined method, without the defects of either system taken by itself. The first cost of the necessary batteries will be less than the saving effected by them in station plant and feeders alone, while the economy in operation will be enormously increased. The battery of each train will be available for the purpose of electrically lighting and heating the cars independently of continued connection with the line, fluctuation in voltage being prevented by permanently connecting and supplying the lighting, heating and other train-service circuits from the separate individual groups of cells so that the change from series to parallel connection of the battery sections will have practically no effect upon the normal

voltage of these circuits. By this arrangement also, a lower and more desirable voltage may be used for supplying the lamps, heaters, etc., than in cases where they have to be placed in series directly across the line. Even the motors themselves may be operated, should occasion require, in parallel or series-parallel from the batteries. As the battery is a fixture upon the train, it does not require removal or handling and the expensive duplication of cells for charging purposes required in ordinary secondary battery car work is entirely done away with. Furthermore, owing to the fact that the cells are almost continually kept up to their normal charged condition by accession of current from the line and motors, the current capacity of the cells that *are* employed can be correspondingly diminished, so that the total cost on account of battery equipment can be vastly reduced as compared with that of an independent battery installation in which a six to eight hours' current supply must be provided for. It is needless for me to add that such a system as I have described is to-day not only quite practicable for roads like the New York elevated, but that it would wonderfully enhance and improve the service and facilitate the handling, dispatching and running of trains, and this at a very material and almost incredible saving over the existing steam locomotive system.

MR. F. W. DARLINGTON:—In connection with transmission on electric roads, it seems to me that two classes of problems have to be solved—ordinary trolley systems operating single light cars—large trolley systems such as the New York elevated, operating trains with heavier cars—and the regular steam railroads. The difference between the elevated roads and the steam railroads is simply that in the case of the elevated road, it is a large trolley road in that it has frequent stops; though not so frequent as on the surface, but still the problem in a *measure* is the same. It seems to me that the solution under experiment on the Third Avenue elevated road with storage batteries will not produce any results directly applicable to the other problems. On the elevated road the trains are running under momentum part of the time, and part of the time they are accelerating their speed as rapidly as possible. For the conditions existing on the elevated roads it may be possible to charge the storage battery sufficiently during the time of running with momentum, to supply the train with all that it will demand at other times. When you come to steam railroad conditions, however, you have the condition for express trains; that power is put on and stays on during an entire run over a section. Take, for example, the "New York and Chicago Limited" over the Pennsylvania Railroad; it runs from Philadelphia to Harrisburg without a stop. There they change engines and make another long run, and during the time it is running, if it is supplied from a central power station electrically, the power taken will be practically the same during the whole run. This we have demonstrated on the Burlington and Mt.

Holly branch of the Pennsylvania Railroad Company in New Jersey. They have considerable grades there. We found that the indicator on the ampere meter at starting the train would jump to a certain point and fall gradually while the train makes a run over the entire road (in proportion to the speed at first)—but after it gets speed, its maximum speed, the indicator will remain practically constant independent of the grades. This is because the speed is varied on the grades, the train going slower up hill than down, but calling for an even supply of power. To such a problem as this it seems to me the storage battery (while at first thought I was struck with the beauty of the solution proposed for the elevated road) will be of no use however, and one other thing in connection with the work over there that applies to the problem of changing over from steam to electricity is the ability to get up speed rapidly. The road there is 7¼ miles long; the last three-quarters of a mile of it are so-called "yard limits," counting from the Burlington end. The distances are all laid off by mile posts. Starting out from Burlington, in six miles we have obtained a speed of 72 miles an hour and maintained it for three miles, and slowed up again so as to have the train under control by the time we reached the yard limits, six miles and a quarter. I am confident that no locomotive on that division of the Pennsylvania Railroad can do that with an ordinary light train and on those grades. Another time we started on a two per cent. grade with a train of cars making the total train load two and a half times what the motors were calculated for, at a point three-quarters of a mile from a mile post which is located at the top of the grade and then practically level. We made that first mile, from mile post to mile post, at the rate of 48 miles an hour. With these results and the ability of motors to start a train quickly, it appears to me that this problem of the substitution of the electric motor for the steam locomotive is not so far off as it has been pictured to-night. Of course, the whole problem, so far as I can see, resolves itself into the method of transmission of power from the generator to the line. This point has not been solved yet. It of course includes the method of collecting the current. The third rail seems to be a good thing if it could be used and be safe, but we have made that 72 miles an hour with an ordinary overhead trolley wire with very little trouble. I am very much interested in the solution of the problems that are under way at the present time, and I think that line being built between Baltimore and Washington is going to give us some very practical results in the method of long distance work. In the matter of grades—we must remember, in first attempting steam railroad work, that our conditions for high speed work are practically the same as for steam railroads. In laying out new roads, grades and sharp curves must be eliminated if we want to obtain high speed.

[Adjourned.]

DISCUSSION CONTINUED IN CHICAGO, OCTOBER 28th.

(Mr. Drake in the Chair.)

MR. H. M. BRINCKERHOFF:—In a general way it may be stated, that the only methods of electric traction that have so far demonstrated their ability to perform such work as would be required on surface steam railroads are some modification of the much abused trolley system. This may take the form of an overhead contact or of a third rail; but the principle of continuous conductor fed from a central station with a direct current of from 500 to 700 volts, is common to all.

We have an example of the overhead arrangement on a large scale in the Baltimore and Ohio tunnel equipment at Baltimore. There they are hauling probably the heaviest train units ever successfully handled electrically, and are in fact doing the work of the largest steam locomotives, under strictly steam railway conditions. This, of course, does not allow of the best economy being obtained, but it demonstrates the ability of electric motors to do even this extremely heavy class of work.

In order to supply the large amount of current required on this system, the overhead contact arrangement used is necessarily heavy, and hence expensive. The cost of this particular form must be so high as to make it unavailable for lines of any great length.

The N. Y., N. H. and H. R. R., on their Nantasket Beach line, have successfully operated an overhead system, the trolley wire used being of a pear or figure 8 cross-section, the same as that used on Clark Street, in this city.

The difficulty experienced here was, I believe, in keeping the trolley on at high speeds, and that this, with other considerations, has proved a drawback is emphasized by the fact that this road is now experimenting with a third rail system.

Other companies might be mentioned who are running lines with a few cars as they say "experimentally." These, however, are sufficient to show that a genuine effort is being made by steam railway managers to get at the facts as to whether there is any economy to be gained by the substitution of electricity for steam on some of their lines.

In elevated railway work we have the Metropolitan elevated railroad operating a third rail system on about 14 miles of double track and handling 1,200 trains per day.

The Lake Street elevated has been changed from a steam to an electric road, using the same equipment as the Metropolitan.

The North Western elevated railroad, now building on the north side of the city, is to be equipped electrically, and the "Alley L," now operating by steam, will in all probability follow suit. Thus we will have in the near future the whole elevated railroad system of Chicago run on a uniform third rail plan, giving the finest service of the kind in the world.

I have read some accounts of an experiment now being tried on the 34th Street branch line of the Manhattan elevated railroad in New York, in which storage batteries are carried on the cars to act as an auxiliary to a third rail. The object is, I believe, to have the batteries help to maintain the voltage toward the end of the line, haul the cars in case of failure of the main power station, and also reduce the sudden loads on the generating machinery. This strikes me as an unnecessary complication, and I do not see why the advantage claimed could not be gained from a stationary battery suitably located.

Having now run hastily over the various systems that are at present in operation, and using them as a basis for our judgment, let us consider what changes or modifications should be made in them to meet the requirements of surface work.

In the first place, in proposing to install an overhead system we are met by the following objections:

1. The danger to employes and passengers caused by poles between the tracks.
2. The expense of an overhead construction.
3. The difficulty of maintaining contact at high speeds.

In the matter of danger to employes, the fact is that in yards where there is often a complicated set of switches, the presence of poles placed at irregular intervals would be a great menace to trainmen and switchmen in making up trains. Frequently having to do the work at night, and being obliged to jump on and off the cars at all times, collisions with the poles in these yards would be almost unavoidable.

I have talked with yardmen, switchmen and trackmen, who work about some of the large railway yards in this city, and they all seem to feel that the presence of poles would be a source of danger to them in doing their work.

As to the expense of an overhead construction, the difficulty arises in supplying the large starting currents required in this class of service. Not only must the conductor have a large cross-sectional area, but the surface contact with the device on the car must be large to prevent burning at the points of contact. This of course means a heavy pole construction which runs up the first cost.

The difficulty of maintaining contact at high speeds, particularly where crossings must be made, is one which will have to be overcome by some radical departure from present methods, such as the trolley wheel and pole.

Some of the objections to a third rail system in surface lines are as follows:

1. Danger to employes, particularly in yards, from the bare rail.
2. Danger to public at grade crossings.
3. Danger to passengers where platforms are used on a level with the track.

1. In judging of the danger to employes, I think we can get a good basis for an opinion from the experience on the Metropolitan elevated, which has been operating a third rail system for more than a year and a half. The work we do in the yards is practically the same as that required on surface lines; switching and making up trains, etc., much of this having to be done quickly and at night. In addition we do such light repair work as is required on the trucks and brakes—removing and replacing brake shoes, often with the bare contact rails within a few inches of the work.

I have looked over our accident reports, which are very complete and include every mishap, however trifling, and in the time we have been in operation we have had scarcely any men burned or injured by the trolley rail in the yards, and such accidents as have occured have been of a trivial nature.

The danger to the public at the grade crossings could be eliminated by omitting the contact rail at such points, and providing for contact by placing a set of shoes on the passenger coaches, and carrying a sufficiently heavy wire through the train to supply the motors as well as the heaters and lights.

In this way such crossings as we have in Chicago which range from 66 to 80 or 100 feet in width could be spanned without losing contact. Additional safety could be gained by having a section of the contact rails on either side of the crossing normally out of circuit, and thrown in automatically either by the approaching train or by the guard gates.

3. The danger to passengers could be best eliminated by elevating the platforms which would have the additional advantage of shortening the length of stops, and materially improving the service. With our elevated platforms, passengers have no occasion to go upon the tracks, and those who do venture, seem to take very great care to avoid the "deadly trolley."

In a general way I do not see that there are any insurmountable obstacles in the way of installing an electric system on surface steam railroads following either the line of an overhead or third rail system.

With such experience as we now have, by giving proper consideration to details and the requirements of the service, we should be able to design a system that would give very satisfactory results.

The question whether it should be a third rail, overhead or storage battery is simply a matter to be decided by the conditions on the particular system considered, and a careful estimate of first cost and maintainance.

It is hardly necessary to state that to get the maximum economy from an electric installation it would be necessary to change the whole method of handling trains on steam roads by breaking up the train units. This hauling of a large number of smaller trains at more frequent intervals, limits us at present to systems having

a heavy suburban traffic where such a change would improve the service, besides accomplishing a gain in the economy of operation.

That a system of electric traction can be so installed to meet the requirements of the heaviest suburban service, I do not for a moment doubt. As to whether the gain in economy over steam will be sufficient to offset the additional interest charges on the cost of equipment will depend upon the local conditions, and the judgment and skill used in equipping to meet those conditions.

I have limited myself in these remarks to such systems as are now in practical use and to such lines of work as our present apparatus seems capable of handling, and leave to those more accustomed to theorizing the wider field of possible future developments.

PROF. STINE:—Have you any data at command with regard to the cost of operating the road?

MR. BRINCKERHOFF:—I am not in a position to give you the exact cost of operating, but it is considerably lower as is shown by the fact that the various railways about the city here in Chicago are going into the third rail system, such as the Lake Street elevated, and other roads that contemplating building.

MR. M. COSTER:—Mr. Brinckerhoff's remarks are very interesting. I will state to you what I think will be the future of the electric locomotive in this country. I think we shall not see, in our time, any electric locomotives applied to cross-country service. They will be used chiefly for suburban service—running light trains at frequent intervals.

The advantages of the alternating current motor are going to solve the problem. With the polyphase motor, we shall be able to carry high tension alternating currents over long distances, and change to very low tension for short distances, and so be able to use the third or fourth rail with great success. Thus we could use a very low potential. I look forward to the time in the near future when the alternating current motor will replace the direct current motor for street railway work.

MR. W. D. BALL:—I would like to ask a question regarding the subject before us to night.—Is cross-country service, or suburban service, the exact topic under discussion?

PROF. STINE:—The discussion at New York took up the whole territory, not only urban and suburban, but interurban and cross-country. Anywhere that we have traffic operated under steam railway conditions, the discussion covers.

MR. BALL:—I rather agree with the last speaker, Mr. Coster, in both positions that he takes, that we shall not for the present see the cross-country railroads operated by electricity, and also that we shall see some developments from the alternating current motor. The great difficulty has been the trouble in obtaining starting torque, and it is a problem which has been worked on for three or four years, but unsuccessfully. The General Electric Company, last spring, announced that they had solved the problem

for street railways. Their idea was to put in a condenser to counteract self-induction, changing the capacity of the condenser. This was found impracticable, so they put in an extra self-induction, and varied that. I have been unable to get any exact data, but I believe that was the idea.

As to the problem of interurban service, I have come to the conclusion that, according to the present developments, it is impossible for us to hope for anything in the near future. The best thing we can do, perhaps, is to transmit high tension alternating currents over great distances, and then transform down. If we have a perfected polyphase motor and controller we can use 40 to 50 volts on the third rails, or we can use rotary transformers and continuous currents. The latter is not simple and is expensive. It is necessary to have the transformer nearly the size of the original machine, that is within 50 per cent. We see that the transmission systems at present are limited to 50 or 75 miles, at a voltage of 15,000 to 20,000. Now, if we wish to transform this into direct current, we would have to put rotary transformers in every 10 or 15 miles perhaps, and transmit at 500 to 700 volts. Reducing the voltage by a static transformer to 500 volts, and putting in a rotary transformer would give you a continuous current at 700 volts. If we must have a station every hundred miles, and sub-stations every fifteen or twenty miles, it is hardly possible to do it with any degree of economy, as compared with steam.

The only point in favor of electricity in interurban service seems to me to lie in the abating of the smoke nuisance. In that way, it would be a great boon to humanity to put in electricity, but as to the economy of it, at the present development of science, I do not see how any saving can be worked out, and unless that can be accomplished, the steam railroads will certainly not adopt the system.

For cases like that of the Baltimore tunnel, there is a great field for electricity, as well as for urban surface and elevated roads.

I rather lean to the opinion, that for surface roads the third rail system would be dangerous, especially to the ignorant public, and that we had better stick to the small unit and overhead system until we get some perfected battery system, but for elevated roads it is undoubtedly the best system we have. To sum up, the solution for interurban heavy traffic is not found unless it be in the direct conversion of coal into electricity, with some such scheme as Mr. Jacques's battery.

MR. J. R. CRAVATH:—The only place where we can look forward to any immediate invasion of electricity in the steam railroad field is in suburban service. There is where the wedge is entering at present, as we see in the case of the Nantasket Beach road which is practically a suburban, or rather, a summer resort service. In order to get the advantages of electricity to the fullest

extent for steam railroad work, the steam road must change its methods of operating by cutting up its trains. Trains must be short, not only for the purpose of making the operation economical electrically, as previously mentioned here, but also for the purpose of giving the public better service, and more frequent service, especially during the hours of light load, and in that way compete with the street lines. The latter is going to be (or at least ought to be) the very best argument in favor of the use of electricity in the minds of steam road officers who are considering the question. On the suburban service of the Illinois Central, we all know the conditions are probably as favorable to the application of electricity as on any steam road in this city. Electrical engineers are sometimes apt to think of steam road men as too conservative. However, from conversation with them, I think steam railway engineers seem to be very much inclined to meet electrical engineers half way in this matter. They have not, however, found anything when they looked up electrical matters which seemed to fit their case exactly. For example, suppose the Illinois Central road should decide to adopt electricity for suburban traffic, what would we have to offer them that would perform their service in a satisfactory manner? There is the third rail system, but we have not decided yet by experiment exactly the best form of third rail or the best position for it, or the best way of insulating and protecting it, or the best arrangement of it for switches, crossings and other special work. That these things will be perfected soon there is no doubt, but we are not there yet. The overhead trolley for such a system as the Illinois Central is considered out of the question, I believe, by the engineers of that road, and they are probably right, because of the large contact necessary for such heavy currents, the difficulties of high speed at overhead switches and trouble from trolley coming off at high speeds on curves, to say nothing of the trouble in switching at terminals.

I would like to ask Mr. Brinckerhoff what is his opinion as to the best position for the third rail if used on a surface steam road—between the tracks, as on the Liverpool elevated and Nantasket Beach road, or as on the elevated roads in this city.

Mr. Brinckerhoff:—That came up in connection with the elevated roads. The question is, in placing this rail between the running rails, that the distance between the bottom of the motor and the top of the rail shall be ample for clearance. The rail is five inches high, and the motors nine inches from the ground, giving about four inches clearance. That limits your insulator and conductor to about nine inches, and there is danger of contact with the motor casing or brake beam. With the rail at the side, you can take any height you desire, and put in a sub-base of light resistance insulation.

Another point is at the crossings. If you have a conducting rail placed between the running rails, particularly in slip switches,

the third rail being between the running rails gets you into complications. We have had to put in movable contact pieces to spring in and raise the shoe as it comes across. With us the solution has seemed to be to have the rail on the outside. On surface roads it meets with objections when the men are making couplings, etc. Now, after some months working with the third rail on the outside, the men seem to think there is little or no danger from it.

MR. C. L. BROWN:—From first appearances the complications that have arisen on the Nantasket Beach line seem rather formidable. Their presence seems unnecessary on a new line, unless they intend it as purely experimental. The third rail appears to be the future system, certainly for elevated roads; and as Mr. Brinckerhoff has shown us, it is in favor for surface roads, on account of the danger being less than with the overhead construction. His method of getting over grade crossings is a good one, although it is dependent upon the length of the trains, and the locomotive or motor car alone would be unable to cross without a trolley. I am firmly of the conviction, however, that means will be found to enter station limits and grade crossings with perfect safety and without the use of the trolley. In regard to the alternating current motor: I noticed that Dr. Duncan recently said that after ten years of searching we are still looking for the successful single phase alternating current motor for railway work. From what we have just heard and from information to be obtained in other quarters, we may look to the polyphase motor with its lower voltages and consequent less danger, for the future development in railway work. In regard to the Illinois Central railroad, perhaps, the main difficulty is in securing sufficiently firm contact for the work required; but on the whole I should say the conditions were ideal for either system of electric traction. Referring to the question of torque raised by Mr. Ball, there can be no general expression connecting the starting and running torque of direct and alternating current motors. It is a question of design, and as the motor referred to by Mr. Coster will give at starting from five to six times the running torque, so the direct current motor may be so designed as to give any desired relation between the starting and the full load running torque.

THE CHAIRMAN:—(Mr. Drake:) Some ideas have occurred to me in connection with this proposition, having had some little experience years ago in the steam railway line, although nothing which could be used as a basis of argument or contention to-night. If we suppose a long distance line to be equipped electrically, we have a number of features which must be taken care of. These lie chiefly in the fact that the trains are infrequent and very heavy, and in case we attempt to cut them in two, as is suggested in electric practice, I doubt if the railway companies would consent, although in passenger traffic they might rather allow two

trains of four cars each than those now comprising seven, ten and even more cars; but in freight traffic we have the very difficult problem, for which I can see in electricity no immediate or satisfactory solution.

A locomotive running under the maximum speed that is usually attained with a loaded train, requires not less than 1,000 horse-power, perhaps more, so that in transmitting that amount of power, not only to that train but to trains going in the opposite direction, the first cost of equipment and feeders must be very high. For short distance traffic, I think the electrically propelled train is the best any one can imagine. I believe the Illinois Central could be equipped with either the third rail or overhead wire system. The principal objection to the latter is the difficulty of maintaining the contact at high rates of speed. I think that contact might be made so that it would not be a serious objection. Perhaps midway between the present trolley and the "cross-bow" used abroad, we might find a plan for preventing the slippage we have here.

The third rail system has some features which are difficult of getting around. If you divide up your line into sections, or according to the "block system," you must have automatic switches. Here we would meet serious opposition from the locomotive engineers, who are seldom called upon to bridge over difficulties of such a character. With a locomotive they are usually able to get to a station or siding. Under this proposed plan, if a switch fails, with the train midway between blocks, there is a very decided wait—one which would cause much interruption to the service, and one which I believe would raise strong opposition and protest.

The feature in connection with steam road practice is the heavy freight duty required and consequent power consumed, yet for long distances I believe the best way to be through the polyphase system, or some system of alternating current, which could be reduced to a practice which would be applicable to such a road.

Mr. Rugg:—I have given this subject very little special thought. One remark made by Mr. Brinckerhoff, however, about the use of the storage battery on the Manhattan elevated railway of New York, attracted my attention. It seems to me that one great advantage would be in the reduced cost of the copper in the feed wires, because the batteries would take the heavy load which would come on the feed wire in starting the train, and the feeders would be taxed with a very small load continuously. I was interested in the remark made concerning the alternating current motor. We all know that the alternating current motor has had a very bad character, but at the same time it has been striving vigorously to live down its bad reputation, and I think it is succeeding very well. People are beginning to believe in the alternating current motor.

The matter of torque seems to bother a great many persons, even at this late day. The experience of late has been that torque does not enter into the question at all. The alternate gives practically as much torque as will a direct current motor and just as efficiently, so I do not think that we need to be at all afraid of the matter of torque in connection with the alternating current motor, even where the torque required in starting is very great. I have seen polyphase street car motors which would give a static torque of five or six times the full load torque, and that, we must all admit, is sufficient for practical purposes.

For train work, a motor is being used now and working on a train in a very successful manner, starting easily and giving very satisfactory service.

THE CHAIRMAN:—In your experience, what is the highest rate of speed recorded?

MR. BRINCKERHOFF:—The highest speed we have ever attained was in a test with a four car train with four motors. Our ordinary equipment is with two motors. Our longest section is about 8000 feet. We have attained about 35 miles an hour with a fully loaded train. By "loaded train" I mean a train which was loaded for the test with iron weighing about 14,000 lbs., making an equivalent of ninety-two passengers in the car. This train made about 35 miles an hour with two motors. With four motors, it made about 38½ miles an hour, and the train was still accelerating. With the reduction given three to one I would add another gear of $3\frac{3}{16}$ to one. It is merely a matter of gear. The contact shoe is of soft cast-iron, and when first used, seems to wear very rapidly, but after they have been used for a few months, they do not seem to wear as fast as they did the first month, as they seem to take on a kind of glaze or hardening on the surface.

PROF. STINE:—Do you find that the third rail pits to any extent?

MR. BRINCKERHOFF:—No; unless possibly at stations, in starting. We have had some pitting, but the top of the rail is as bright as a silver dollar.

MR. DRAKE:—The question of operating in steam railway conditions would not, in your opinion, operate badly on the shoe?

MR. BRINCKERHOFF:—I do not see why it should hurt the shoe, except at crossings, where you are obliged to allow the shoe to drop and take it up again. We have put in inclines about one inch in five feet. The shoe makes a little click as it strikes it. You could take care and lose no speed by making that a more acute angle.

MR. COSTER:—Both alternating and direct current motors can be made to have any reasonable starting torque. So many people confound the polyphase motor with the synchronous motor. But I want to assure Mr. Ball that we can give him all the starting torque he can use. These motors are now applied with the

greatest success to cranes in foundries where the work is very exacting—where the mould has to be let down very carefully, and where the crane has to lift a very heavy load and requires a large starting torque.

MR. BALL:—Are you manufacturers in position to put the polyphase motor in the market for street car work, and if not, what is the difficulty?

MR. COSTER:—In street car work there are so many details, such as the third rail, controllers, etc. However, the motor is there, and the results have been far in excess of our most sanguine expectations. It has excelled the direct current motor in many respects, and I think the alternating current polyphase motors will be the motors of the future.

PROF. STINE:—Do you recall any data from the tests made at Pittsburgh on the two-phase street car motor?

MR. COSTER:—I only know they have made some tests with very satisfactory results. We are not quite prepared to furnish data, but I will say that I was surprised to see them do so.

MR. BALL:—Why cannot we put in the double trolley and use the third wire?

MR. COSTER:—This question would be determined by circumstances, the same as with the direct current motor.

PROF. STINE:—I would like to ask Mr. Rugg if he has any data on hand of their tests?

MR. RUGG:—I have no definite data on hand; except in a general way, they are built for heavy torque, and we get between five and six times the static torque, and the controlling of them is easily accomplished. As far as efficiency goes, it compares very favorably with the direct current street car motor.

MR. BALL:—Do you put resistance in series with the armature and get it out afterwards?

MR. RUGG:—Yes; by means of resistance we get the starting torque.

THE CHAIRMAN:—We have had an interesting discussion this evening on existing methods of practice here in this country, and in some cases, abroad. For myself, I would invite comparisons or remarks on some of the other proposed systems, notably, the Heilmann machine,—and whether, in the opinion of those present the plan of this inventor could be used practically and with success in this country.

MR. J. R. CRAVATH:—I do not like to say very much about it. It is hard for me to see where the advantages of such a machine as the Heilmann locomotive would come in. It carries its own steam power plant, which never seemed to me to be of the best design for the work; it also carries its own electrical plant, and I also question whether that is the best design for the work; it piles this all on one set of trucks, and employs a small army of men to keep it going. Of course there may be some theoretical advantages, but I don't care to say much about it.

PROF. STINE:—The subject under discussion naturally invites attention to the storage battery in relation to the future of electricity in the operation of railways. As the storage battery situation exists at the present time, such a relation seems entirely out of the question, owing not only to the excessive weight of the storage batteries, but to the rapid deterioration of plates, especially when these are made light enough for traction purposes. Some time since, I had occasion to make what was to me a very interesting calculation with reference to the possibility of the application of the storage battery to heavy traction work. I was led to do this from results of a purely scientific character, and wish to state emphatically at the outset that this calculation has no commercial basis at present.

Some years ago, during an investigation of the storage battery, I was enabled to obtain an actual storage of one horse-power hour in 29 pounds of battery. This was under conditions which were far from ideal. By reducing the weight of the containing vessel and the dimensions of the battery, and doing away with all unnecessary electrolyte, etc., the same result was indicated from a gross battery weight of 12 pounds per horse-power hour. This is a laboratory possibility, but unfortunately there are some questions of an electrolytic character which prevent its having any commercial application. On this basis a calculation may be made, showing what would be the result of applying such a battery on the operation of say our best developed express service on railways.

We may assume that the average traction weight on drivers on our best express engines is about 80,000 pounds, while the front truck carries a further weight of 40,000 pounds. Such locomotives are usually provided with great water and coal endurance. We may take these figures at 13,000 pounds for coal and about 30,000 pounds for water; this, carried on a tender weighing from 30,000 to 40,000 pounds. A locomotive of this size will, at 50 miles per hour, develop about 1,250 horse-power, and is in service for about 150 miles at a time. Allowing 50 per cent. reserve, this will give four and one-half hours' service, or a total of 5,625 horse-power hours. Counting now 12 pounds of battery per horse-power hour, we have a net weight of battery of 67,500 pounds. This would seem to be just a little under the average weight of the tender and its contents. Taking the weights of the electric locomotives so far built, it would be possible to carry this entire battery weight on the driving axles, making the total weight tractive, unless for reasons of great speed, when a leading truck would be necessary. The total weight of the battery and locomotive would not be practically in excess of the steam locomotive weight mentioned above, (120,000 lbs.) The gain in weight would be that of 80,000 pounds charged up against the tender.

As to the bulk of this battery, it could be brought within the

space at its disposal in such a locomotive. In summing up our figures, we see that practically little would be gained by using the storage battery in place of the steam locomotive, and the entire question would hinge on the economy of such a storage battery installation over that of a portable steam plant. The object, however, was to show the possibility rather than the economy.

To return from the somewhat ideal possibilities to the problem that we are actually facing to-day, I do not believe that the discussion is at all ended, when we have considered the relative economies existing between the practical steam plants and electric locomotives supplied from large central stations. There are many other considerations which, it seems to me, will eventually be important factors in deciding to what extent steam railways will adopt electricity. In the first place, on a large number of railways the best handling of trains does not seem to obtain very serious attention. The problem seems to be to get trains through. As a consequence, there is a local congestion, especially of freight traffic. This greatly magnifies the problem of change to electric traction. If the flux of trains could be kept near an average, the problem would be greatly simplified, and better management on the part of train despatchers could accomplish much toward securing this. But if those writers who have written and have been competent to express an opinion are to be trusted, railway operation will, in all probability, undergo important modifications, and it is not too much to believe that the shortening up of the trains, with an increase in the number of train units, will be the tendency. This, of course, will be entirely favorable to electric traction.

In spite of all our carefully matured calculations, bearing on the question of relative economy, should the financial conditions of the country at large greatly improve, these would have less weight than we at present attach to them. The coal item is a comparatively small one on a large and well-managed system, and our assumptions of what would be the character of electric traction, if it were adopted, should be taken with great allowance.

After all, there are questions of desirability which will add weight to those of economy, and experience will suggest modifications from time to time which may put an entirely different aspect on the whole problem. Without being too sanguine, it does seem that if a few engineering points were settled soon, that electric traction would gain a rather rapid hold upon the railroads of the country. At present, electrical engineers themselves are in doubt as to whether polyphase motors have any decided advantage over direct current motors. Then, too, the matter of contact between the conductors and the moving trains has not reached such a stage of development as to inspire confidence in its reliability and permanence. A few of these points once settled, we may look for rather rapid progress.

[Adjourned.]

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VOLTS VS. OHMS.

Speed Regulation of Electric Motors.

BY H. WARD LEONARD.

The control of the speed of an electric motor from a state of rest to a state of full speed is a problem of rapidly growing importance to the electrical engineer. The operation by means of electric motors, of elevators, locomotives, printing presses, traveling cranes, turrets on men-of-war, pumps, ventilating fans, air compressors, horseless vehicles, and many other electric motor applications too numerous to mention in detail, all involve the desirability of operating an electric motor under perfect and economical control at any desired speed from rest to full speed.

The most commonly practiced method of controlling the speed of an electric motor for such applications at present, involves the use of ohmic resistance in the circuit of the motor armature, which resistance is varied to control the speed of the motor.

The use of an ohmic resistance for controlling the speed of an electric motor results necessarily in a waste of energy and in an unstable control of the speed. The object of this paper is to endeavor to show the advantages arising from the use of a system of motor control having several modifications, but all of which involve the idea of controlling the speed of an electric motor by controlling the E.M.F. generated in its armature circuit, and without using any regulating resistances in that circuit.

I shall consider only the control of a single motor, that is, I shall not consider the control of several mutually dependent motors by grouping in series and series parallel. I shall also limit the consideration to that of a continuous current motor.

Fig. 1 shows the first and simplest form of the E. M. F. system of motor speed control.

S is an engine or other source of power operating at a practically constant speed.

G is a generator.

M is the motor.

E is a circuit of constant E. M. F. which supplies current for exciting the fields of G and M.

It will be noticed that the fields of both G and M are independent of the E. M. F. and current of their armatures. The field of M is practically constant. The field of G is variable from full strength to zero strength by manipulation of the controlling rheostat C in the field circuit of G. It will also be noticed that there is no rheostat in either the field or armature circuit of the motor M which is to be controlled.

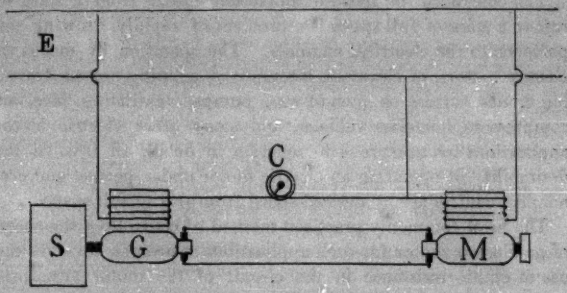

FIG. 1.

It will be evident that by varying the field strength of G we can vary the E. M. F. generated in the armature circuit from zero to the full working E. M. F.

In order to make definite comparisons, let us assume certain figures for the full E. M. F. and current of G. Suppose its full E. M. F. to be 250 volts, and its full working current to be 100 amperes. Also let us assume that the resistance of the armature of M is .05 ohms, giving a C^2R loss in that armature of 2 per cent. of its rated capacity, when the full working current is flowing. Let us assume that the full speed under full torque is 500 revolutions per minute. For the sake of simplicity and because it does not affect the practical accuracy of the deductions, let us neglect the slight losses due to Foucault currents, hysteresis, fric-

tion and the slight ohmic resistance of the rest of the armature circuit.

Suppose that our motor is to drive a large printing press, such, for example, as is used for printing calico, and that it is required of us that we shall drive the press at any desired speed from rest to full speed, and that we shall maintain any such intermediate speed practically constant even though the torque should vary from mere friction torque to the maximum torque of operation.

Let us suppose that the friction torque is represented by 10 amperes through the armature of M, and that the maximum torque of operation is represented by 100 amperes through the armature of M. We have now fixed all the conditions necessary, in order that we may determine the exact performance of the motor.

If, by manipulation of the controller C, we allow a slight and gradually increasing current to flow through the field of G, the E. M. F. at its brushes will gradually rise from zero upward, since the armature of G is being constantly driven at its full speed. When it is generating one volt at its brushes, a current will flow through the armature of G, due to one volt acting through .05 ohms, causing 20 amperes to flow through M. If the press be under full torque it will not start with this current. When we have five volts at brushes of G, we have 100 amperes through M, and the armature is just about to start; but since any motion of M would cause the development of a counter E. M. F. which would reduce the current below 100 amperes, it does not start as yet.

As soon as we raise the E. M. F. at brushes of G above five volts, the armature of M moves at a rate of speed sufficient to develop a counter E. M. F. of five volts less than at G.

Thus if we have six volts at G, the armature of M will move at a rate of speed sufficient to develop one volt counter E. M. F. and permitting the flow of the proper current for the necessary torque, that is 100 amperes.

I call attention to the fact that since the field of the motor is constant, the counter E. M. F. is directly proportional to its speed.

At full torque and full speed, the counter E. M. F. would be 245 volts, five volts being dropped by the passage of the 100 amperes through the ohmic resistance of .05 ohm.

Similarly if G has 125 volts at its brushes, that is one-half of its full voltage, and the full torque current of 100 amperes be in

use, the counter E. M. F. of M would be 120 volts and its speed would be 120÷245 of its full speed, that is M would run at 245 revolutions per minute or practically speaking at one-half of its full speed.

Similarly, with one-tenth of the full E. M. F., that is with 25 volts at the brushes of G, the speed of M under full torque current would be 20÷245 of its full speed, that is 41 revolutions per minute or approximately one-tenth of its full speed.

Suppose now while M is running thus at 41 revolutions per minute under full torque, the entire load be thrown off, except merely the friction the torque current of which we have assumed as 10 amperes.

Instead of five volts drop, due to the 100 amperes through the .05 ohm, we now have only 10 amperes through .05 ohm, or .5 volt drop, and the resulting momentary increase of current through M causes slight acceleration of its armature until its counter E. M. F. is 24.5 volts instead of 20 volts, which it was under full torque. That is, its speed is now under friction load $\frac{24.5}{245} \times 500$, or 50 revolutions per minute.

Hence we see that when operating the motor at one-tenth of its full speed of 500 revolutions per minute and while under full torque, we can throw off the entire load and experience a change in the speed of only 9 revolutions per minute.

Now let us consider the same motor under same conditions excepting that it is connected as usual to a constant E. M. F. circuit of 250 volts, and that the speed is controlled by an ohmic resistance in the armature circuit, the field being in shunt directly across the line.

If we are to operate the motor under full torque, we must have the full 100 amperes flowing through its armature, and if it is to be operated at one-tenth of its full speed its counter E. M. F. must be 245÷10 or 24.5 volts. This means that we must drop in the rheostat 220.5 volts out of the 250 volts constantly impressed. By having 220.5÷100 = 2.2 ohms in the rheostat we can secure this condition of affairs. But now we are wasting 100 × 220.5 = 22,050 watts in the rheostat and only utilizing in the motor 2,450 watts.

Perhaps the worst feature, however, about the conditions now prevailing, is that we have practically no control over the speed under change of torque. For example, suppose as before that we

now throw off the entire load, leaving only the friction load. Under the reduced torque the motor speeds up until its counter E. M. F. plus the drop of E. M. F. in the rheostat again equals the line E. M. F. When this condition is realized, we have the friction torque current of 10 amperes flowing through the resistance of 2.2 ohms in the rheostat, and causing a drop of only 22. volts, and consequently the counter E. M. F. of M must be 250—22. = 228 volts and its speed must be $\frac{228}{250} \times 500 = 456$ revolutions per minute.

That is, by throwing off the full load, our motor has jumped from 41 revolutions per minute to 456 revolutions per minute,

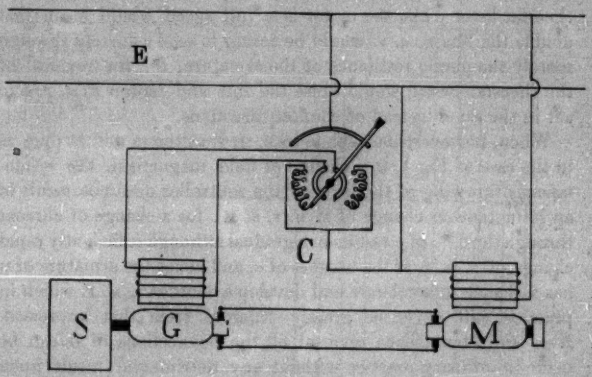

FIG. 2.

a change of 415 revolutions in this case as compared with 9 revolutions in the former case, the change in speed under the same conditions being nearly 50 times as great by the system of ohmic control as by the system of E. M. F. control.

Suppose we are again operating at one-tenth speed under full torque and therefore have 2.2 ohms in our rheostat. Now let the torque increase only 12 per cent. which must be expected in any kind of commercial practice. To keep the armature in rotation will require 112 amperes but the ohms in circuit, 2.25, will only permit the passage of 111 amperes with 250 volts impressed, hence the increase of 12 per cent. in torque will cause the armature to

come to rest. In the system of control by volts instead of ohms on the other hand, the speed would only be reduced from 41 revolutions per minute to 40 revolutions per minute which change would not be perceptible.

I have gone thus fully into the detailed figures of the cases considered, believing that the radical difference between the systems of control can only be appreciated fully by such concrete examples as I have given.

I now desire to call attention to the fact that in the speed control by ohms, the operator can, by moving the lever of his rheostat, change the volts upon M as fast as he can move his hand. This is a frequent cause of burning out of armatures. In the case of a reversing rheostat, the instantaneous throwing of the rheostat lever while the motor is at full speed would mean that double the line E. M. F. would be acting to send a current through merely the ohmic resistance of the armature, for the reversal of the rheostat switch would cause the line and motor E. M. F.'s to act in the same instead of counter directions.

When, however, the change in E. M. F. at the motor is due, as in the case of Fig 1, to a change of field magnetism, the instantaneous throwing of the lever of the controller does not result in an instantaneous change of E. M. F. at M; for a change of current through the field of G results in a gradual although sufficiently rapid change of E. M. F. at the brushes of G, and hence the armature of M has a chance to accelerate and develop a counter E. M. F. which in practice will never be greatly different from that impressed. Even an instantaneous reversal of the connections of G can be made in ordinary practice without any detrimental result upon the generator or motor, because of this appreciable time required to reverse the magnetism of G. By various well known methods the time required for this reversal of magnetism can be varied over wide limits.

Fig. 2 shows the changes in connections of Fig 1 necessary for the operation of a motor whose motion is to be reversed.

Fig. 3 shows a modification of the general system in which the source of E. M. F. is composed of several different generators in series with each other and having a system of several conductors, upon each of which a different constant potential is maintained, so that by connecting the motor armature across different conductors, different E. M. F.'s are obtainable at the motor armature. With two generators and three conductors we can obtain three re-

versible, different automatic speeds. Similarly, with three generators and four conductors we can get six reversible, different automatic speeds. This modification of the system is especially suited to the distribution of power in an isolated plant such as a large manufacturing establishment.

I now come to the modification of the E. M. F. system of motor speed control in which the substitution of E. M. F. for ohms in the motor circuit for the purpose of controlling its speed, is most conspicuous.

We found, when considering the case of the rheostat control with the motor running at $1 \div 10$ speed and with 100 amperes

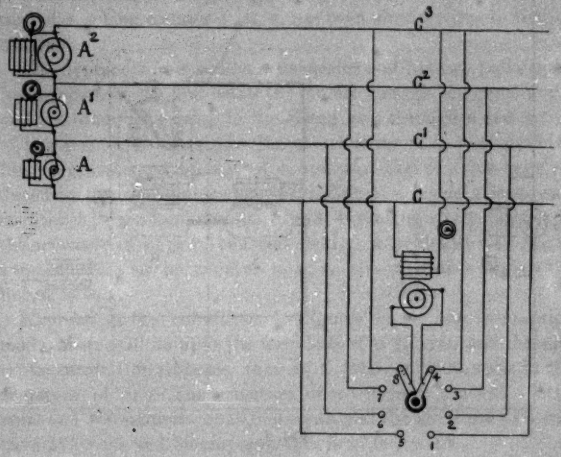

FIG. 8.

through it, that the rheostat had to absorb and dissipate 100 amperes $\times$ 220.5 = 22,050 watts while only 2,450 watts were utilized in the motor.

As has been shown, this loss in the rheostat is troublesome, not only because of the waste of energy, but especially because of its interference with all positive control.

Evidently what is needed is to substitute for the rheostat a device which will absorb the 220.5 volts and 100 amperes, and, instead of wasting them, convert them into useful work.

Fig. 4 shows how this is accomplished by one modification of the E. M. F. system of motor speed control.

G is a source of 125 volts constant E. M. F.

S is a shunt-wound dynamo connected across the constant E. M. F. and hence running at a constant speed.

R is a dynamo mechanically connected to drive or be driven by S, and running at a practically constant speed.

The field of R is excited by the main line E. M. F. and is independent of the E. M. F. of its armature and of the current through its armature. It has a variable and reversible field rheostat in

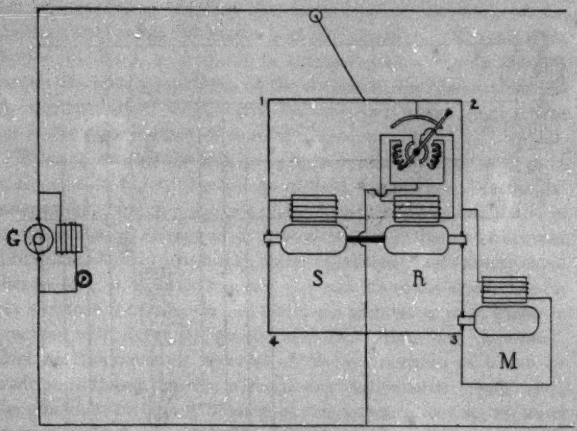

FIG. 4.

circuit by means of which the magnetism of the field of R may be varied and reversed at will.

M is the working motor. Its armature is in series with the armature of R across the line. Its field is excited by the main line E. M. F. and hence is independent of the E. M. F. or current of the armature M.

Let us suppose that the armature of S is wound for 125 volts and 100 amperes. The armature of R for 125 volts and 100 amperes, and the armature of M as in the former illustration for 250 volts and 100 amperes.

I will neglect the armature losses for the sake of simplicity, and because they do not materially affect the conclusion.

Suppose that as before we want to run M at one tenth of full speed under full torque, full speed being 600 revolutions per minute and corresponding to 245 volts counter E. M. F. and full torque being that due to 100 amperes in the full field.

At first let us have the rotary transformer RS so adjusted that the fields of R and of S are both fully excited. Each end takes a slight current through its armature. Both ends are motors, and they divide between them the friction load.

Now let us weaken the field of R until its field strength is only nine-tenths of its full strength. In this weaker field, R tends to run faster; but in doing so it is obliged to drive faster the armature of S, whose counter E. M. F. has been almost equal to that of the line.

The dynamo S now acts as a generator and has two paths open for its current, the first being the circuit through the generator G and the other path being in the closed loop through R and M.

The E. M. F. of G balances that of S, but the E. M. F. of R which formerly was equal to that of G and also that of S, has been reduced by the weakening of its field, hence S sends a large current through the local circuits 1, 2, 3, 4, causing a large torque in the armature of M, in its constant field. M evidently will run at a speed such that its counter E. M. F. plus that of R equals the line E. M. F.

Expressing the conditions in figures under the assumption made, there will be upon the terminals of M 25 volts and through its armature 100 amperes, that is, a total of 2500 watts in the armature of M. The armature of R will have $125-25=100$ volts and 100 amperes or 10,000 watts, and the armature of S will have 125 volts and 80 amperes, that is 10,000 watts.

The generator G produces 20 amperes at 125 volts or 2,500 watts, which, by the method described, is transformed into 25 volts and 100 amperes at the working motor.

By continuing the weakening of the field of R, we finally have a field of no strength, and hence R becomes inert and we have the full line E. M. F. of 125 volts upon the 250-volt motor M, which, consequently, runs at half speed. Under these conditions no energy is transformed by the rotary transformer RS. If, now, we reverse the connections leading current to the field of R, and send a gradually increasing current around its field, its voltage is

added to that of the line instead of being counter as heretofore, until finally its full voltage of 125 being added in series with the line E. M. F. of 125 volts we have upon M 250 volts and it runs at its full speed. While R is thus adding to the line volts, it of course is acting as a generator instead of a motor, which it formerly was, and is now driven by S, which acts as a motor instead of a generator.

I call attention to the fact that the current capacity of all three armatures, R, S and M, is equal, but the full E. M. F. of R and S is only half that of M, which means that the K. W. capacity of R and S is each only half that of M.

The rotary transformer R can also be designed to run at much higher speed than is demanded for the working motor, since it can be perfectly balanced and is free from any side or end thrusts and has a minimum friction.

There are other modifications of the E. M. F. system of motor speed control which I am not able to describe at present, but as in the case of those described above, the underlying feature is, to insert or cut out E. M. F. instead of ohms in the armature circuit of the motor when we wish to change its speed.

Since many have thought this system of motor speed control limited to a few peculiar cases, and also limited to peculiar kinds of generators and motors, I give in the table below instances within my own knowledge, showing the kind of machinery operated and the size and make of the motor used:

Kind of Machinery Operated.	Size of Motor.	Maker of Motor.
Traveling Cranes.	1 K. W. to 50 K. W.	Crocker-Wheeler, Eddy, Edison, Waddell-Entz, Billberg, C. & C., Westinghouse.
Passenger Elevators.	5 K. W. to 40 K. W.	Edison, Eickemeyer.
Mining Hoists.	10 K. W. to 125 K. W.	C. & C., Crocker-Wheeler.
Turrets on Men-of-War.	25 K. W.	General Electric.
Billet Shifter in Rolling Mill.	30 K. W.	Crocker-Wheeler.
Heilmann Locomotive.	8 of 50 K. W. each.	Brown
Cloth Printing Press.	25 K. W.	Edison, General Electric.
Newspaper Printing Press.	50 K. W.	Unknown.
Universal Boring Machine.	5 K. W.	Unknown.

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